UTILIZATION OF ENSET FIBER IN CEMENT CONCRETE PAVEMENTS TO REDUCE RISK OF PLASTIC SHRINKAGE CRACKS

BY:

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CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Science and Technology University a dissertation entitled "***Utilization of Enset Fiber in Cement Concrete Pavement to Reduce Risk of Plastic Shrinkage Cracks”*** in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering specialized in Road and transport Engineering.

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I FikruBedada, declare that this thesis is my own original work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

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APPROVAL PAGE

This MSc thesis entitled with ***"Utilization of Enset Fiber in Cement Concrete Pavement to Reduce Risk of Plastic Shrinkage Cracks"*** has been approved by the following examiners in partial fulfillment of the requirement for the degree of Masters of Science in **Civil Engineering (Specialized in Road and Transport Engineering)**

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DEDICATION

To Kume Balcha and Yosa n Fikru

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ACRONYMS AND ABBREVATIONS

ACI -American concrete Institute

ASTM-American standard test methods

BS-British Standard

CRR-Crack Reduction Ratio

FRC-Fiber reinforced concrete

HMA -Hot mix Asphalt

HPC-High performance concrete

LVDT-Linear voltage differential transformers

PCC-Portland cement concrete

RH-Relative Humidity

SCC-Self Compacting concrete

SP-Supper Plasticizer

UHPC-Ultra high performance concrete

W/b- Water to binder ratio

EF0-Control concrete mixture without Enset Fiber

EF0.5- Concrete mixture with 0.5 % Enset Fiber

EF1.0- Concrete mixture with 1.0 % Enset Fiber

EF1.5- Concrete mixture with 1.5 % Enset Fiber

EF2.0- Concrete mixture with 2.0 % Enset Fiber

ABSTRACT

Concrete pavements are well suited for hot areas and heavy traffic loading. Its purchase being easier than asphalt, cement concrete pavement offers excellent advantages in terms of durability and economic efficiency. In the context of Ethiopia, constructing cement concrete pavements have additional advantages than asphalt pavements on saving foreign currency because of the absence of local production of asphalt related to cement production of about 18 local cement factories. Past local researchers have indicated that, rigid pavements provide superior economic advantages over flexible pavements. However these researchers have also indicated that the longevity of rigid concrete pavements can be affected by several factors, particularly due to cracks formed at early age .Thus, the urgency to secure technologies or innovative indigenous ideas for the control of early age and long term cracking is of paramount importance. Plastic shrinkage cracking is one of the major causes of degradation for concrete components like cement concrete pavements constructed in hot weather, in which a high percentage of the surface area is exposed to drying. Factory produced non-metallic fibers have been often used in concrete mixtures in order to reduce the width of the plastic shrinkage cracks, through stitching the concrete surface particles together. This research evaluates the early age plastic shrinkage crack risk reduction of cement concrete pavements, by using local "Enset[1]" fiber which is inexpensive by product of Enset during "kocho[2]" production.

In this research Restrained Plastic shrinkage cracks were quantified using image analysis software for concretes with Enset fibers of 0%, 0.5%, 1.0%, and 1.5% by volumes. From this research study, it is observed that Enset fibers can significantly reduce the width of plastic shrinkage cracks.

Keywords– Hot weather concrete, Enset fiber, plastic shrinkage cracking, cement concrete pavement.

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[1]Plant native to Ethiopia (***Enseteventricosum)***, commonly known as false banana.
[2] Common food produced from stem of Enset plant.

1 INTRODUCTION

1.1 Background

In Ethiopia construction of road projects using cement concrete pavements is emerging in addition to air fields mainly due to its economic advantages related to asphalt pavements. Cement concrete pavements are economical than asphalt pavements especially in Ethiopian condition due to saving of hard currency. According to ketema (2016) a total of $105,526.13 USD will be saved per kilometer if the road utilizes rigid pavement rather than flexible pavements. But adequate maintenance to ensure the longevity of this pavement is difficult compared to asphalt pavements in case of deterioration. This condition indicates that the need of special attention on durability of concrete parallel to other physical properties of concrete to minimize deterioration of pavements. One of the main defects in cement concrete pavements is the presence of cracks. One of the main factors that contribute to the cracks in pavements is that due to shrinkage. Even if it is difficult to eliminate shrinkage cracks can be reduced to an acceptable range.

1.1.1 Types of Shrinkage

Generally there are four different types of shrinkage for concrete: plastic shrinkage, autogenous shrinkage, drying shrinkage Carbonation shrinkage. Plastic shrinkage and autogenous shrinkage happen at an early age of the concrete, while drying shrinkage and Carbonation shrinkage takes place over a long period of time.

Plastic Shrinkage

Shrinkage of this type manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or sub grade is believed to be the reasons of plastic shrinkage. In case of floors and pavements where the surface area exposed to drying is large as compared to depth, when this large surface is exposed to hot sun and drying wind, the surface of concrete dries very fast which results in plastic shrinkage.

Plastic shrinkage can be reduced mainly by preventing the rapid loss of water from surface. This can be done by covering the surface with polyethylene sheeting immediately on finishing operation; by fog spray that keeps the surface moist; or by working at night. Use of small quantity of aluminum powder is also suggested to offset the effect of plastic shrinkage. Similarly, expansive cement or shrinkage compensating cement also can be used for controlling the shrinkage during the setting of concrete.

Drying Shrinkage

Just as the hydration of cement is an everlasting process, the drying shrinkage is also an everlasting process when concrete is subjected to drying conditions. The drying shrinkage of concrete is analogous to the mechanism of drying of timber specimen. The loss of free water contained in hardened concrete, does not result in any appreciable dimension change. It is the loss of water held in gel pores that causes the change in the volume. Under drying conditions, the gel water is lost progressively over a long time, as long as the concrete is kept in drying conditions. Cement paste shrinks more than mortar and mortar shrinks more than concrete (Gambhir, 2014). Concrete made with smaller size aggregate shrinks more than concrete made with bigger size aggregate.

Autogeneous Shrinkage

In a conservative system i.e. where no moisture movement to or from the paste is permitted, when temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogeneous shrinkage.

Carbonation Shrinkage

Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide [Ca (OH) ^{2}] gets converted to calcium carbonate and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in normal atmosphere. Carbonation penetrates beyond the exposed surface of concrete very slowly. The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium. Carbonation is accompanied by an increase in weight of the concrete and by shrinkage. Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place. Carbonation of concrete also results in increased strength and reduced permeability, possibly because water released by carbonation promotes the process of hydration and also calcium carbonate reduces the voids within the cement paste. As the magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage, this aspect is not of much significance.

1.1.2 Mechanism of shrinkage Crack in general

Shrinkage cracks occur when concrete members undergo restrained volumetric changes (shrinkage) as a result of drying, autogenous shrinkage or thermal effects. Restraint is provided either externally (i.e. supports, formworks, and other boundary conditions) or internally (differential drying shrinkage, reinforcement). Once tensile strength of the concrete is exceeded, a crack will develop. The number and width of shrinkage cracks that develop are influenced by the amount of shrinkage that occurs, the amount of restraint present and the amount and spacing of reinforcement provided. These are minor indications and have no real structural impact on the concrete member.

Plastic-shrinkage cracks are immediately apparent, visible within 0 to 2 days of placement, while drying-shrinkage cracks develop over time. Autogenous shrinkage also occurs when the concrete is quite young and results from the volume reduction resulting from the chemical reaction of the Portland cement.

The schematic pattern of crack development when stress is relieved by creep is shown Figure 1.Cracking can be avoided only if the stress induced by the free shrinkage strain, reduced by creep, is at all times smaller than the tensile strength of the concrete. Thus, time has a twofold effect the strength increases, thereby reducing the danger of cracking but, on the other hand, the modulus of elasticity also increases so that the stress induced by a given shrinkage becomes larger. Furthermore, the creep relief decreases with age so that the cracking tendency becomes greater. A minor practical point is that, if the cracks due to restrained shrinkage form at an early stage and moisture subsequently have access to the crack, many of the cracks will become closed by autogenous healing.

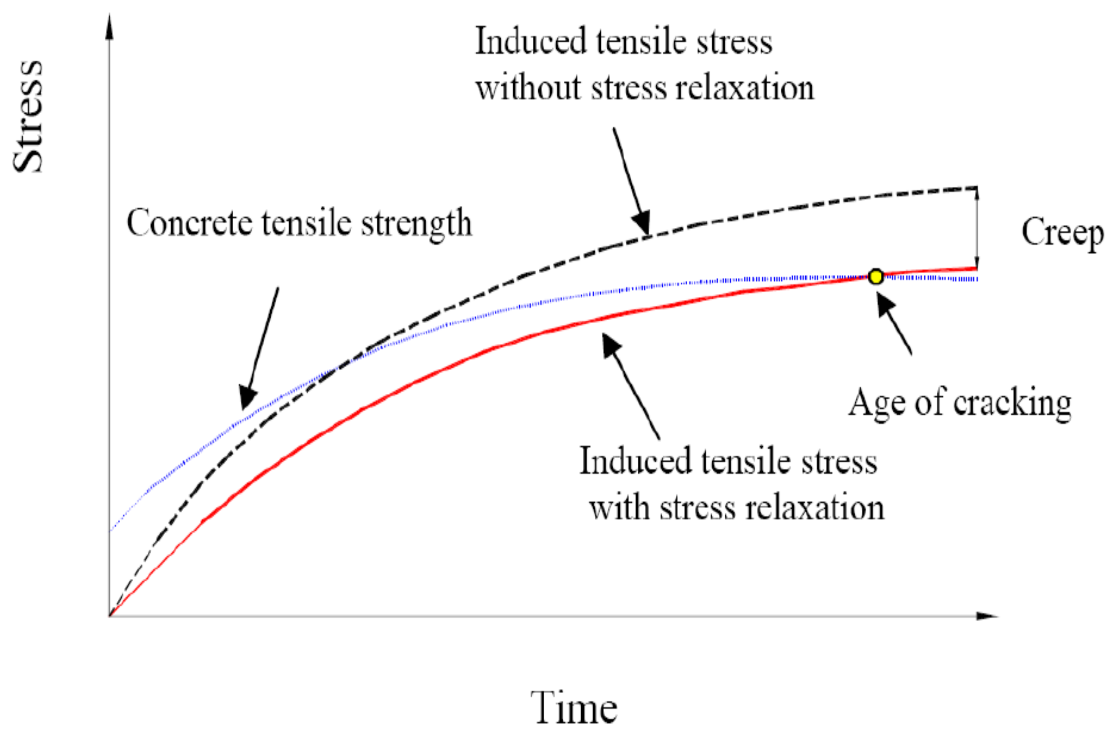

Figure 1 Mechanism of Cracking (from Neville 1996)

This paper focused on reduction of plastic shrinkage crack which is one of the main early age shrinkage cracks using Enset fiber which is cheap byproduct of Enset during qocco production.

1.1.3 Plastic Shrinkage Crack in Particular

Plastic shrinkage cracks are one of the main causes that affect the durability of Portland Cement Concrete (PCC) pavement, or rigid pavement as it is sometimes called, refers to the rigid concrete layer of the pavement structure that is in direct contact with the traffic. The concrete can be modified to reduce the risk of plastic shrinkage cracking in a number of ways, including the addition of non-metallic fibers, which are materials that are added to the mixture to enhance the properties of the fresh concrete against plastic shrinkage.

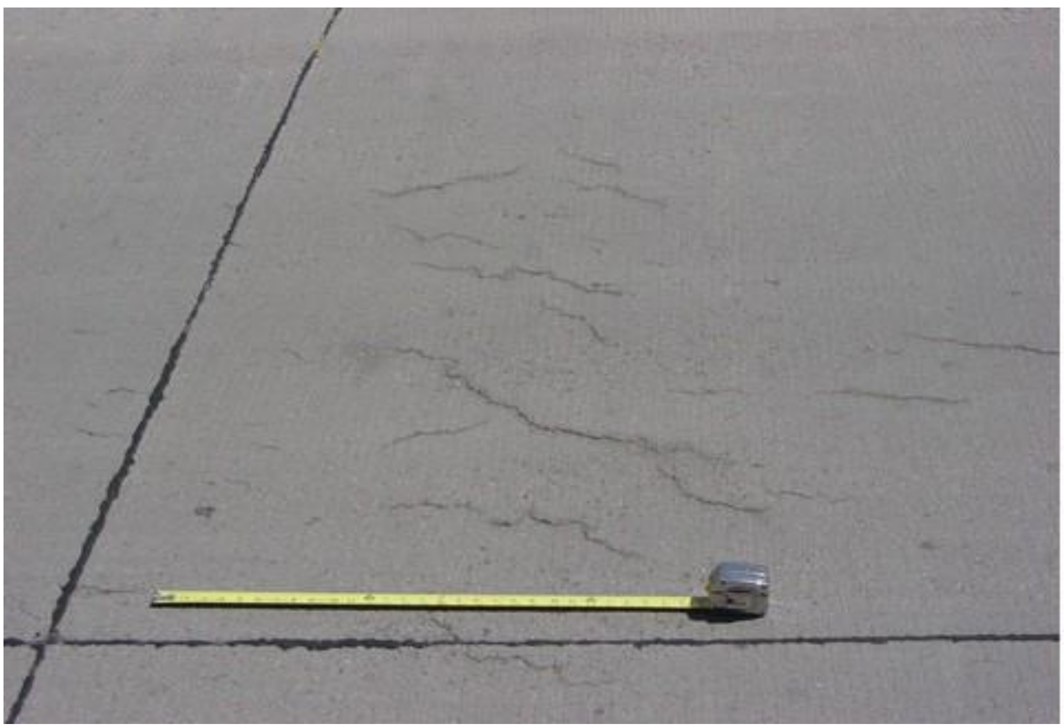

Figure 2 Typical plastic shrinkage cracking in rigid pavement **(Jordan, 2014)**

Plastic shrinkage is caused by the loss of pore water from the concrete due to evaporation which results in a build-up of negative capillary pressure. Environmental conditions with high evaporation rates increase the magnitude of the plastic shrinkage and are characterized by conditions with a low relative humidity, direct sunlight as well as high wind speeds and air temperatures.

Plastic shrinkage will however not cause cracking unless the shrinkage is restrained. A restraint would result in an imposed strain and if this imposed strain is at any time more than the strain capacity of the concrete, cracking would occur. The strain capacity of concrete reduces significantly when the concrete stiffens, i.e. around the initial setting time. This phenomenon is shown in Figure 3. The cracking typically initiates at around the initial setting time of the concrete.

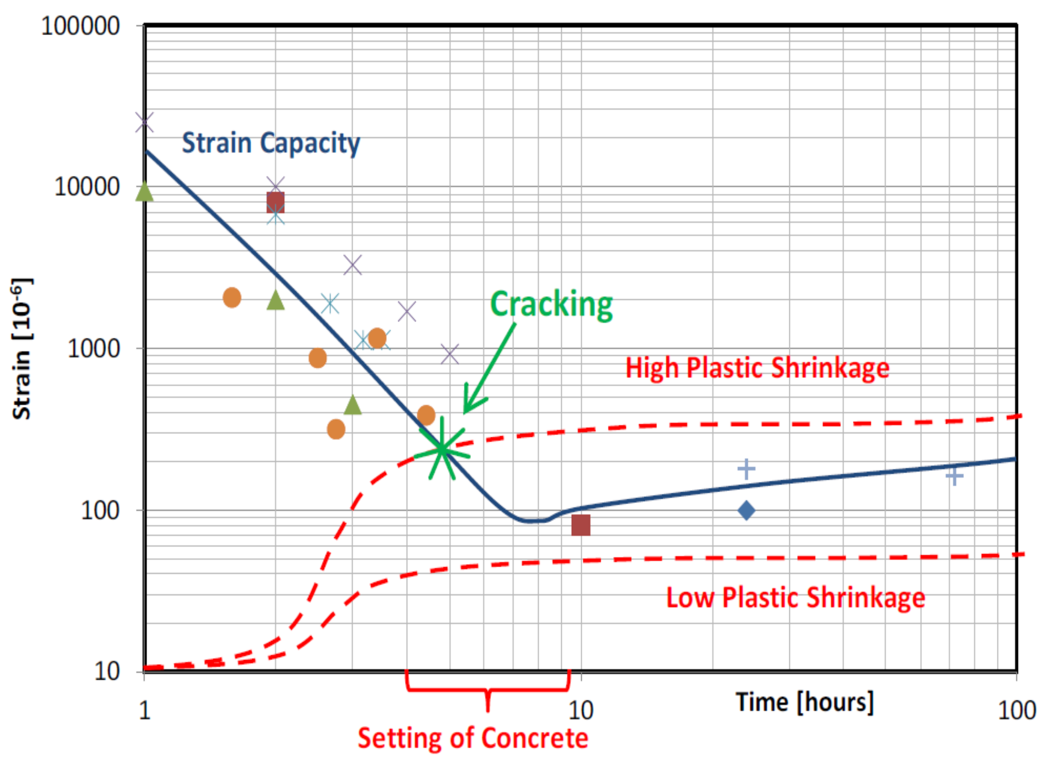

Figure 3 the typical strain capacity of concrete with a schematic representation of induced plastic shrinkage **(Boshoff, December 2012)**.

Plastic shrinkage cracking mainly occurs in horizontal concrete elements with large surface to volume ratio (e.g. slabs, pavements, industrial floors). As a result of water evaporation, hydraulic pressure (capillary pressure) builds-up in the pore system which in turn causes the concrete to shrink (ACI 305 R, 2007). If the concrete is restrained (e.g. by the formwork, reinforcement, change of sectional depth, difference in shrinkage in different parts of the concrete, etc.) and it has not gained enough tensile strength, the shrinkage will lead to cracking.(WP Boshof, 2013) The cracks are similar to the cracking that occurs in clay soil as it dries.

1.2 Statement of the problem

Owing to the shortage of foreign currency in the country and increased supply of cement, the Ethiopian Road Authority is highly promoting the construction of rigid concrete pavements particularly in the hot and /or windy dry regions of the country. Because Long period of extreme heat may lead to thermal expansion of paved surfaces and may compromise flexible pavement integrity which causes rutting and the greater the wind speed the more quickly it will remove heat from HMA during paving. Early-age shrinkage cracking of concrete pavements is a common problem in hot weather concrete. When the induced tensile stress is larger than the tensile strength of the concrete, cracking occurs.

The presence of early-age cracking in concrete pavements increases the effects of spalling due to sulfate and chloride penetration, and corrosion of steel reinforcement, thus resulting in premature deterioration and potential structural deficiencies in the cement concrete pavements.

Concrete pavement repair is expensive and can result in significant traffic delays. Accordingly, there must be necessary to reduce the extent of plastic shrinkage cracking using cost effective material like Enset fiber and thereby prevent the premature deterioration which can minimize maintenance.

1.3 Limitations

Fiber percentages of content of more than 1.5 % (volume) for plastic shrinkage was not studied due to the absence of technology that disperse Enset fibers uniformly in to the concrete.

1.4 Objective

General Objective of the research is to study the use local Enset fiber in concrete pavements for the reduction of plastic shrinkage crack without affecting other physical properties of concrete.

Specific objectives of the paper is

- To determine amounts of Enset fiber which can minimize plastic shrinkage cracks to an acceptable crack area
- Checking the effects of Enset fiber on Compressive strength, Flexural strength and Tensile strength of concrete.

1.5 Organization of the research

The organization research paper is as follows. Chapter 2 discusses the literature review on the effect and applications of non-metallic fibers. Chapter 3 covers materials used and test methods during the experimental process. Chapter 4 covers the test results of the laboratory experiments and discussion on the results, Chapter 5 provides the relevant. Finally, Chapter 6 provides relevant recommendations for further investigation

2 LITERATURE REVIEW

2.1 Introduction

This literature review surveys past studies related to effects of using non-metallic fiber on plastic shrinkage crack. Plastic Shrinkage cracking of concrete pavements can be affected by many different factors, including material properties, restraint types, construction methods, environmental conditions, etc. Many researchers have performed laboratory studies and literature reviews on utilization of non-metallic fiber to reduce plastic shrinkage cracking potentials of concrete using different non-metallic fibers. The American Society for Testing and Materials (ASTM) provide test methods and specifications that can be used to analyze the plastic shrinkage behavior of concrete. In this section, the previous studies and test methods are reviewed.

2.1.1 Causes of plastic shrinkage

Plastic shrinkage is caused by a rapid loss of water on the concrete surface before the concrete hardens. This loss of water can be caused by many reasons, such as evaporation or suction by a dry sub-base. In fresh concrete, the concrete materials have not formed into a solid matrix and are still surrounded by water. When too much water rapidly evaporates, the water that remains in the concrete will not be sufficient, and voids occur within concrete, leading to the occurrence of plastic shrinkage cracking. In other word, plastic shrinkage cracking occurs when the rate of evaporation of moisture from the surface exceeds the rate at which supply of moisture (via bleeding from the concrete). The concrete surface dries out and shrinks at a time at which it has little strength and hence it cracks.

Water is lost from the concrete mass in two main ways:

- **Drying from the top -**Moisture rises to the top surface of a concrete element during placement – a process known as bleeding. Bleed water dries out mainly from evaporation; when the rate of evaporation exceeds the rate of bleeding, the surface dries and tends to crack.

- **Drying from the base -**Water in a concrete slab may be absorbed into the sub grade or ground below. In addition to affecting bleeding this could significantly increase settlement of concrete and the risk of associated cracking.

The rate of evaporation from the surface is dependent on environmental factors such as Temperature, relative humidity and wind speed. It is not just a hot weather phenomenon, as the combination of these factors may provide the worst conditions in cool weather with low humidity and wind.

Mix design sets the bleed capacity of the concrete. This condition may be changed from hot to cold conditions to suit the finishing operations and crack-control requirements. Concretes with low bleed potential (e.g. those containing a high proportion of fine material such as silica fume, fine aggregate, low slump) are more prone to plastic shrinkage cracking. However, mixes with high bleed characteristics are not recommended as a solution as they give rise to other problems (e.g. increased risk of plastic settlement cracking, crazing, delays in finishing processes, greater long-term shrinkage). Retarded concrete is also more prone to plastic shrinkage cracking because of the increased time that it remains in a plastic state.

Controlling the rate of drying of the surface (evaporation rate) is the key to avoiding plastic shrinkage cracking.

The evaporation rate can be determined from the relative humidity, air temperature, concrete temperature and wind velocity using the nomograph in Figure 4, or equation 1. Cracking is most likely to occur when the environmental conditions give an evaporation rate in excess of 1 kg/m ^{2}/h. It is recommended that precautions be taken when the anticipated evaporation rate is likely to exceed 0.5 k/m ^{2}/h. Uno gives the following equation to calculate evaporation rate.

Uno gives the following equation to calculate evaporation rate

$$E = 5\ ([Tc+18]^{2.5} - r\,[Ta+18]^{2.5)}\ (V+4)\ x10^{-6} \qquad \text{(Uno, 1998)} \ \text{----------- Equation (1)}$$

Where

E = evaporation rate ($kg/m^2/h$)

r = relative humidity/100

Ta = air temperature (°C)

Tc = concrete (water surface) temperature (°C)

V = wind velocity (km/h)

Both the nomograph and the equation are based on evaporation from a water surface and do not hold true after bleed waters have been disappeared from the surface, i.e. after the water sheen has disappeared.

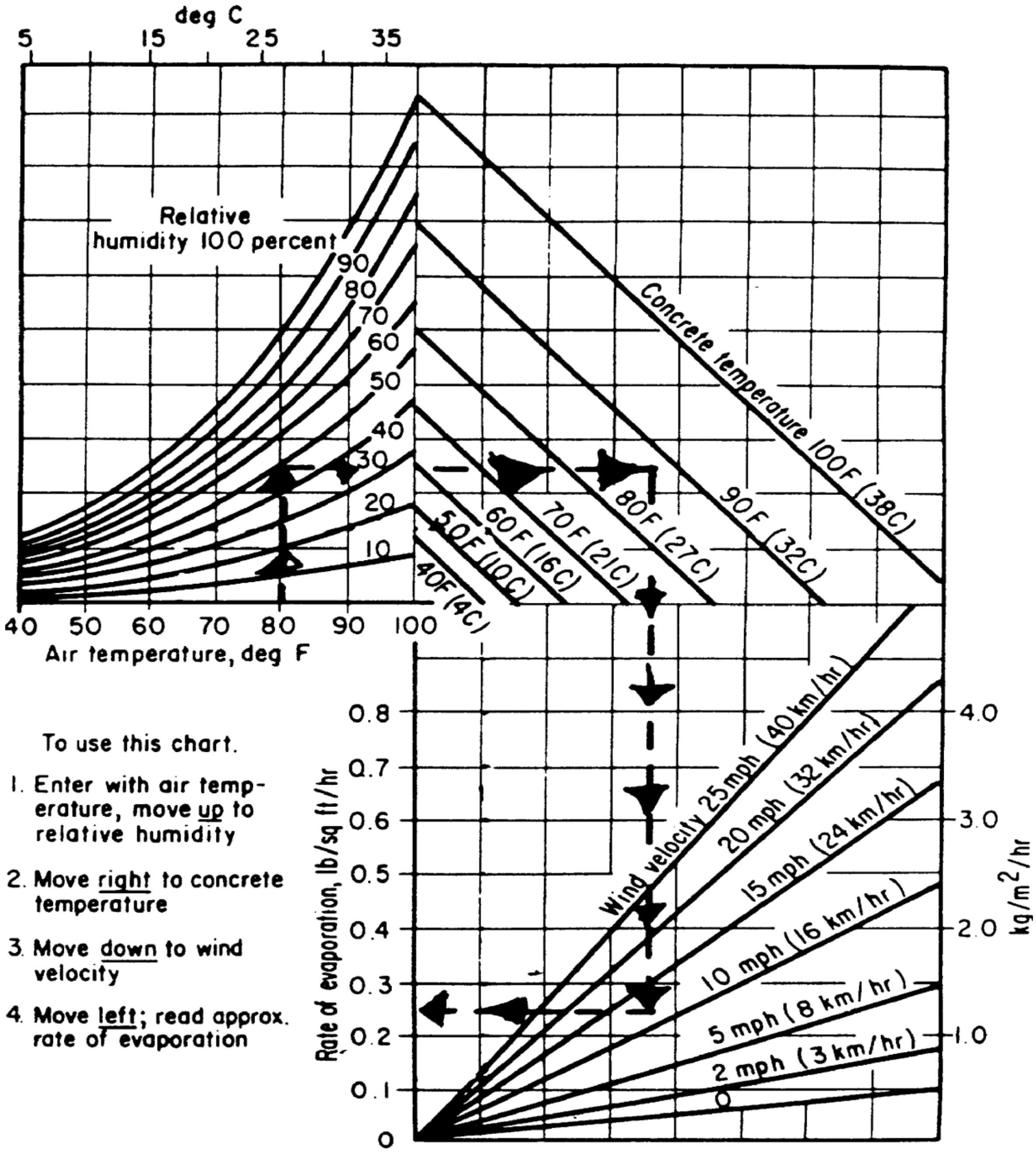

Figure 4 Monograph to estimate Evaporation **(ACI 305 R, 2007)**

2.1.2 Risk of plastic shrinkage cracking

Due to the increment of using modern concretes, such as high performance concrete (HPC), ultra-high performance concrete (UHPC) and self-compacting concrete (SCC), early-age cracking can be highly problematic, as they possess large shrinkage after casting, the risk of plastic shrinkage cracking has increased during the past few decades. The reason lies into the fact that these concretes have relatively low water/binder (w/b) ratio and contain high dosage of water-reducing admixture (super plasticizer). This phenomenon, thus, is not limited only to hot and arid countries and has become a challenge even in the cold Scandinavia. How serious plastic shrinkage cracking in these kind of concretes is, can be comprehended in Kompen's(1994) final remarks in his internal report about a bridge construction project in Norway(Hammer 2007):

> "The plastic cracking phenomenon is regarded the most serious problem met in using low w/b-ratio concrete. There are serious worries that this phenomenon will jeopardize the quality improvements intended by the use of low w/b concretes. By observation in the field and full-scale trials a lot of experience has been gained on how to reduce cracking to a more acceptable level. Understanding of the mechanisms involved has, however, not reached such a level that this cracking can be completely avoided in every construction work. Consequently, it is strongly recommended that research should continue on early age cracking problem, to develop both basic understanding and practical measures."

Plastic shrinkage Cracks accelerate the ingress of harmful fluids, affecting the durability of reinforced concrete structures

2.2 Main factors affecting plastic shrinkage cracking

The research done by (Bjøntegaard Ø, 1998) reported a comprehensive investigation on the analysis of the effect w/b-ratio, paste volume, cement type, sand/Aggregate-ratio and super-plasticizer. Researchers such as Sivakumar, Bushoff, Pelisser and Feranando have done their experimental investigations on the use of fiber reinforcement to prevent plastic shrinkage cracking. The concrete mixture proportions and environment conditions defines the concretes potential for plastic shrinkage. Most of them carried out their experimental investigations on concretes with relatively high water/binder ratios (w/b> 0.6) and relatively high amount of fine aggregate to provoke plastic shrinkage.

Some of the major factors which can affect the plastic shrinkage cracking of cement concrete discussed as follows.

2.2.1 Water/cement ratio

Water/cement ratio significantly affects the plastic shrinkage cracking tendency. Assuming constant mixture constituents, higher w/c ratio causes more bleeding water and vice versa (Fernando Pelisser, 2010). In case of high w/c ratio, thus, it takes longer time for the surface water layer to disappear due to evaporation and consequently delays the capillary pressure build-up in the pore system. Moreover, it is fact that a lower w/c ratio causes less bleeding (in conventional concrete) and thus increases the risk of cracking (Samman, 1996). On the other hand w/c ratio has an inverse relation with the concrete strength. Research (Samman, 1996) has shown that high-strength concrete mixtures (containing more cement) have low bleeding rate and subsequently higher risk of plastic shrinkage cracking. An optimized w/c ratio can, thus, reduce the risk of plastic shrinkage cracking, while without so much decrease of the strength of the concrete.

2.2.2 Admixtures

Accelerators and retarders have a strong influence on the plastic shrinkage cracking tendency. Some experiments (WP Boshof, 2013) showed that accelerator admixtures cause higher plastic shrinkage and total crack area, while retarders act contrary. However, other experiments (O.Esping, 2005)showed that excessive usage of retarder admixtures may increase the risk of plastic shrinkage cracking due to the slower strength gain of the concrete.

On the other hand, super plasticizer (SP) reduces the need for water in the concrete mixtures i.e. less bleed water. This reduction of surface water may however not increase the risk of cracking, as the SP modifies the surface tension and prevents or delays the onset of plastic shrinkage crack formation). Nevertheless, SP acts as a retarder and delays the hydration which means longer dormant period and slower strength gaining rate. Experiments on SCC have shown that a higher SP dosage increases the cracking tendency of the fresh concrete (O.Esping, 2005).

2.2.3 Fines content

Fines such as fly ash, silica fume, slag, etc. lead to a larger total specific surface area of the binder, and narrower pores. Consequently, the water that is supposed to be transported to the concrete surface will be trapped inside and adsorbed by the fine particles, resulting in lower bleeding rate compared to a concrete with lower volume of fines. According to(Cohen, 1990)higher surface area of the particles leads to higher tensile capillary pressure and eventually higher probability of plastic shrinkage crack formation. Moreover, experiments performed by (O.Esping, 2005) showed that silica fume increases the crack tendency in the concrete, despite of the evaporation reduction. Accordingly, using high proportion of fine material in the concrete mixture is not favorable as regards to plastic shrinkage cracking.

2.2.4 Depth of the concrete section

A deeper concrete member typically experiences more settlement. As a result, more water is being transported to the concrete surface trough the pore system leading to a larger water accumulation on the surface. This means that the surface water layer evaporation takes longer time, causing delay in capillary pressure build-up. Consequently, a deeper concrete section is less prone to plastic shrinkage cracking (Van Dijk, 1971). However, due to the high degree of settlement, the concrete may instead be vulnerable to settlement cracking, typically formed above the reinforcement bars, which may facilitate the ingress of chlorides and other harmful substances.

2.2.5 Curing measures

Plastic shrinkage cracks can be avoided through several post-casting curing measures. These measures in general aim at reduction of the surface water evaporation. For instance, sealing the concrete surface (e.g. covering the concrete with plastic sheet) decreases the evaporation rate and consequently can lead to a crack-free concrete.

Compensating the evaporated water is another way to protect the fresh concrete against plastic shrinkage cracking. Fogging the concrete surface, on one hand, reduces the evaporation rate through increasing the ambient relative humidity, and on the other hand, replaces some lost surface water due to evaporation. In addition, using a wind breaker to prevent or reduce the air flow over the concrete surface can be another efficient way to reduce the evaporation (Uno, 1998).

2.2.6 Hot weather

Hot weather may be defined job-site conditions that accelerate the rate of moisture loss or rate of cement hydration of freshly mixed concrete, including an ambient temperature of 27 °C (80 °F) or higher, and an evaporation rate that exceeds 1 $kg/m^2/h$ (ACI 305 R, 2007).

According to (ACI 305 R, 2007) “Plastic shrinkage cracking is frequently associated with hot Weather concreting in arid climates. It occurs in exposed concrete, primarily in flat work such as cement concrete pavements and may develop in other climates whenever the evaporation rate is greater than the rate at which the water rises to the surface of recently placed concrete by bleeding”. It is believed that the main driving force behind this phenomenon is rapid and excessive loss of water, which mainly takes place in form of surface water evaporation.

Occurrence of hot weather problems are mostly in the summer, but the associated climatic factors of high winds, low relative humidity and solar radiation can occur at any time, especially in arid or tropical climates. Hot weather conditions can produce a rapid rate of evaporation of moisture from the surface of the concrete and accelerated setting time, among other problems. Generally, high relative humidity tends to reduce the effects of high temperature. When wind velocity exceeds 8 km/h, the risk of plastic shrinkage cracking is significantly elevated, and precautions should be applied to concrete elements (Scanlon, 1987) In Ethiopia about 4.8% of lands has arid/hot climate (ClimaTemps.com, 2014).The temperature map of Ethiopia is shown in Figure 5.

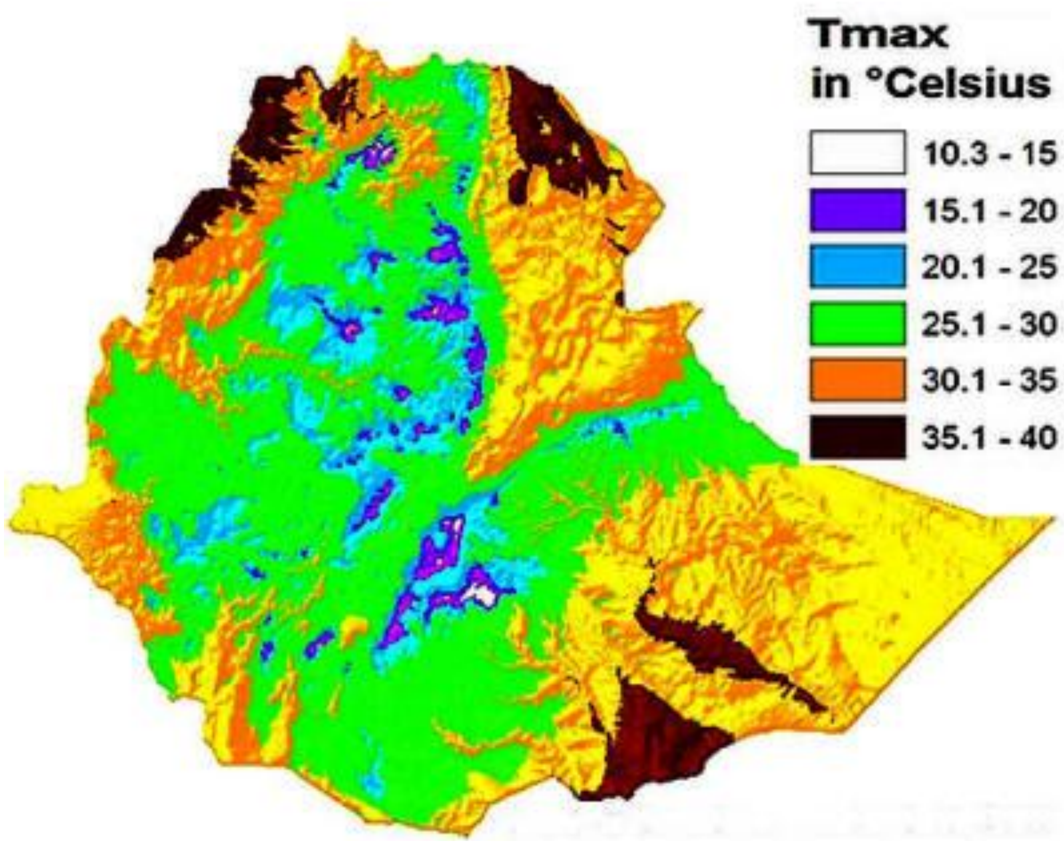

Figure 5 Temperature map of Ethiopia (www.national parks- worldwide.info/eaf/ Ethiopia-weather.html)

2.3 Test methods to quantify plastic shrinkage

In the past, many experimental methods have been proposed to determine plastic shrinkage cracking. Most of them focus on parameters that describe crack width, area and length. Evaporation and bleeding capacity of fresh concrete are commonly used. Since fiber addition is considered as a promising solution to solve plastic shrinkage cracking; most test methods have been used to test fiber reinforced concrete. ASTM C 1579 "Standard test method for evaluating plastic shrinkage cracking of restrained fiber reinforced concrete using steel inserts" test methods was used in the reasearch to quantify plastic shirnkage crack.

2.4 The effect of ambient conditions on experimental results

Most of the experimental studies on plastic shrinkage cracking available in the literature have ambient conditions that give high evaporation rate. The main factors regarding the evaporation rate are high temperature, low relative humidity and high wind velocity. The evaporation of water from the concrete surface is the predominant cause of plastic shrinkage.

According to (Bjøntegaard Ø, 1998), autogenous shrinkage is believed to contribute to what seems to be plastic shrinkage cracking. In some cases, there are cracks even if evaporation of water is prevented; it means it cannot be plastic shrinkage cracking. In the hardening phase autogenous shrinkage can contribute to considerable tensile stress and cracking risk. The ASTM C 1579 standard ambient conditions to measure plastic shrinkage cracking are an air temperature of 36±3 °C, relative humidity (RH) of 30±10 % and a wind velocity of 4.7 m/s.

2.5 Effect of non-metallic fiber

When non-metallic fibers included in concrete mixture, the properties of the concrete changes in relation to the amount and types of fiber added. Because Non-metallic Fibers have a tendency to reduce the width of the plastic shrinkage cracks, through stitching the concrete surface particles together. The fibers only play a role when cracking develops, and they are thus useful primarily for post-cracking control.

Experiments done by (Sivakumar, 2006) studied how to control plastic shrinkage cracking in concrete by adding Polypropylene fiber up to a dosage of 0.5% by volume. The concrete was placed in a slab mould of dimension 500x250x75mm.The slab has a stress riser of 55mm height at the center and two base restraints of 35mm height at 35mm from both ends, along the transverse direction. In addition to these risers, a bolt and nut arrangement was provided at the ends to restrict longitudinal movement of the concrete slab from the edges and to provide additional restraint, increasing the potential of cracking at the notch. The slabs were placed in to an environmental chamber having, constant temperature of 35±1°C, a relative humidity of 40±1% and a wind velocity of 6m/s. An increase in non-metallic fiber dosage resulted in a clear crack width reduction, but it also caused a decrease in workability. According to the study by (Sivakumar, 2006) this decrease in workability restricts the maximum dosage of polypropylene and polyester fibers to an optimal level of 0.25% by volume based on the workability range of 50-75mm. In the case of glass fibers, a dosage up to 0.38% by volume did not affect the workability. The main results from this study were:

- The plastic shrinkage cracking was reduced significantly (50-99% compared to plain concrete without fibers) by fiber addition
- In order to maintain good workability the maximum content of non-metallic fiber was 0.25 % volume.

Research done by (P.A.Dahl, 1988)discussed the influence of fiber length based on the results from an investigation on the influence of 8 types of Krenit fiber on the plastic shrinkage cracking. From these experiments the optimum fiber length seems to be somewhat larger than the maximum aggregate size (16mm). The positive effect of fibers on reducing shrinkage cracking found in this investigation corresponded well with the results from other investigations.

(Nemakumar Banthia, 1996) Had studied the plastic shrinkage cracking potential of cement based materials when used as a bonded overlay. With steel fibers of 0.5% to 1%volume fractions, restrained shrinkage cracking were tested with the novel technique and it was concluded that the steel fibers not only reduced the maximum crack width but also caused multiple cracking in the composite up to a fiber volume fraction of 0.5%. At 1% fibers by volume, only minimal cracking was seen to have occurred even under a particular severe environment.

(Nemkumar Banthia, 2016) Studied the effectiveness of polyolefin fibers in controlling restrained shrinkage and thermal cracking in concrete at a temperature of 38 °C with a relative humidity of 5%. Four types of polyolefin fibers were used in their study. A new technique developed by the authors was employed for this study. In this technique, fiber reinforced concrete to be tested was laid on top of a fully hardened base concrete that provided the bottom restraint and this resulted in cracking in the freshly placed overlay. It was found that crack widths exceeded 1 mm in plain concrete..

(Soroushian, 1995) Found that polypropylene fibers, at comparatively low fiber volume fractions, significantly reduced the total crack area and the maximum width of crack of slab surfaces subject to restrained plastic shrinkage movements. Also, it was concluded that longer fibers of 19 mm length generally performed superior than shorter fibers of length 13 mm. However, at certain volume fractions of fiber addition, the effect of fiber length did not show a satisfactory performance in controlling plastic shrinkage cracking.

3 MATERIALS AND METHODS

3.1 Introduction

The materials used in the study are aggregates, cement, water, and Enset fibers. Major physical tests of concrete at fresh and hardened states have been done in order to study the effect fiber in addition to plastic shrinkage cracking measurement.

3.2 Materials

3.2.1 Aggregate

River sand and crushed gravel found in Ethiopia were used in this study. All aggregate were conditioned in the laboratory environment for 24 hrs and the moisture content was adjusted to compensate for the absorption capacity of the aggregate before mixing. Both the fine and coarse aggregate met the standard Gradation requirements according to (ASTM)C 33.

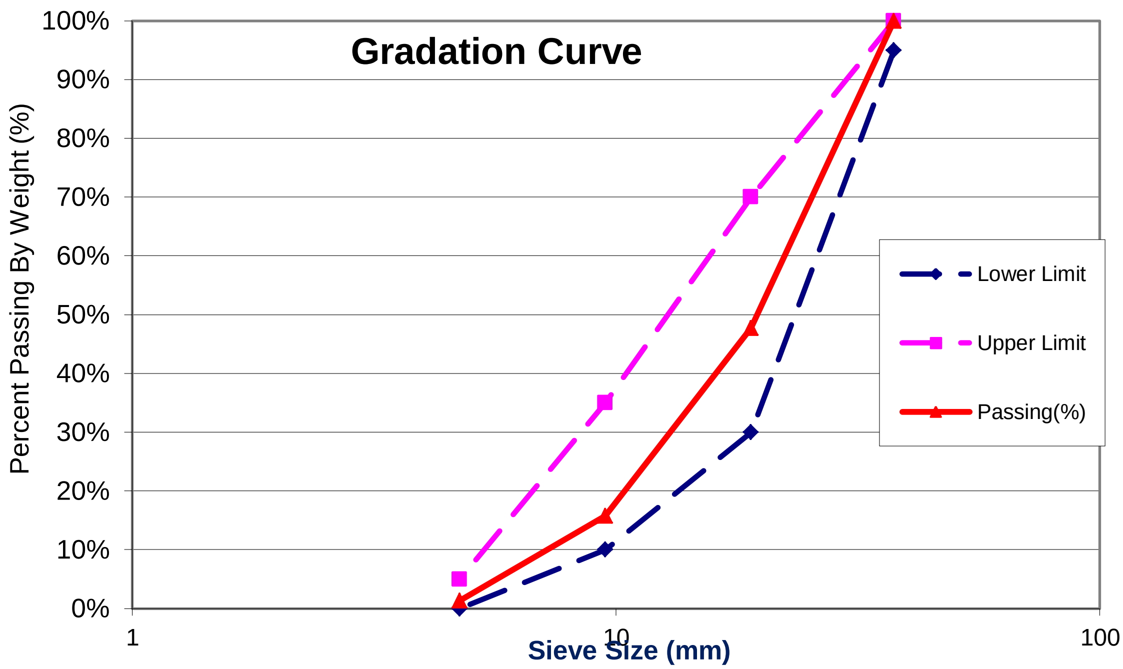

Figure 6 Gradation chart of coarse Aggregate

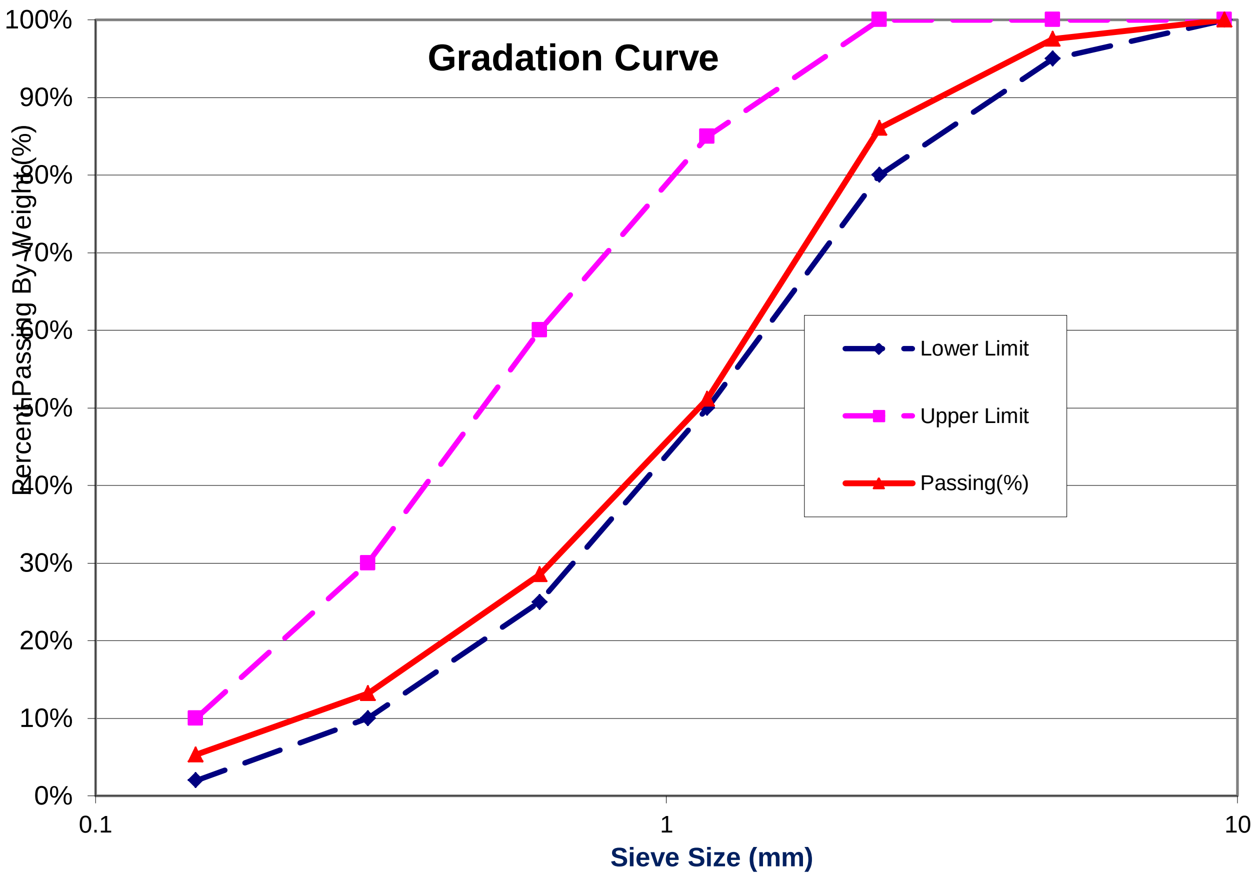

Figure 7 Gradation chart of Fine Aggregate

Table 1 Physical properties of aggregates

Type	Specific gravity	Fiennes modulus	Absorption capacity (%)	Loose Density(kg/m^3)
Fine Aggregate	2.57	2.9	2.14	1589
Coarse Aggregate	2.85	6.7	2.08	1654

3.2.2 Cement

Commercially available ordinary Portland pozzolana cement supplied by Dangote Cement factory was used for all mixes in the study.

Table 2 Physical properties of ordinary Portland cement

Density(g/cm^3)	Blaine(cm^2/g)	Soundness (mm)	Setting time (min)		Compressive strength (Mpa)		
			Initial	Final	3 days	7 days	28 days
3.14	3.19	1.27	87	325	21.7	31.2	42.5

3.2.3 Enset Fiber

Enset fiber was collected from local markets of Addis Ababa. The collected fibers length was minimized in to smaller pieces of about 20 mm in length. To characterize the tensile strength of single fiber, diameter and load measured. The moisture content was measured by conventional method at room temperature.

Figure 8 Measuring diameter of single fiber to characterize tensile strength

Figure 9 Measuring Load capacity of single fiber to characterize tensile strength

The average tensile strength of 15 randomly selected samples of Enset Fibers is summarized in Table 3.

Table 3 Physical properties of Enset Fiber

Average Diameter (mm)	Absorption capacity (%)	Average Strength (Mpa)
0.02	0.87	23.0

Figure 10 Manual cutting of Enset Fiber in to smaller pieces

3.2.4 Water

The experiment used tap water to mix ingredients of concrete.

3.3 Experimental methods

In order to evaluate the factors in the concrete mix designs that affect the plastic shrinkage cracking of concrete, a number of tests are conducted. According to the condition of the concrete when it is being tested, these tests can be grouped into two categories:

1. Fresh concrete tests
2. Hardened concrete tests.

Fresh concrete property tests evaluate the following properties of concrete: slump, unit weight and restrained plastic shrinkage test. Three basic mechanical properties at different ages were conducted for the hardened concrete state obtained from the mix designs: compressive strength, flexural strength, and splitting tensile strength. These tests were conducted to evaluate the ability of the Enset fiber reinforced concrete mix to meet the requirements for the intended applications in concrete pavements. For each concrete mix, the tests considered in this study are summarized in Table 4 along with their ASTM and BS standard test method designations.

Table 4 Experimental plan

		Levels	Test Methods
Experiments	Fresh concrete	• Workability test (slump)	• (ASTM) C 143
		• Unit Weight	• (ASTM) C 138
		• **Plastic shrinkage measurement**	• (ASTM C1579)
	Hardened concrete	• Compressive strength of concrete (3,7,28 days)	• (BS.1881)
		• Flexural strength of concrete (3,7,28 days)	• (ASTM) C-79
		• Splitting Tensile strength of concrete (3,7,28 days)	• (ASTM) C-496

3.3.1 Mix Design

The concrete mix design has been carried out for various proportions as per ACI 318 Standard and arrived at final mix proportion. A total of five concrete mixtures (Table 5)were investigated in this study. One mixture consisted of a control mixture without Enset fiber the other four mixtures were made by modifying the control mixture with the addition of 0.5, 1.0, 1.5, & 2%Enset fibers to it.

Table 5 Mix proportions

Fiber Content (%)	Code	Cement (kg/m^3)	Water(kg/m^3)	Fine Aggregate(kg/m^3)	Coarse Aggregate(kg/m^3)
Normal Mix	EF0.0	380	193.8	676.21	1146.10
With 0.5% Fiber	EF0.5	380	193.8	671.13	1137.49
With 1.0 % Fiber	EF1.0	380	193.8	666.054	1128.88
With 1.5 % Fiber	EF1.5	380	193.8	660.97	1120.27
With 2.0 % Fiber	EF2.0	380	193.8	655.894	1111.66

3.3.2 Workability test

The slump test was performed following the procedures of ASTM C 143"Slump of Hydraulic Cement Concrete". To avoid changes due to operator, only a designated operator conducted the workability test. The inverted slump cone used for this test is shown in Figure 11.

Figure 11 conducting workability test of concrete using slump.

3.3.3 Unit weight of concrete

The Unit weight was done as per the procedures of ASTMC 138 “Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of concrete “as shown in Figure 12”.

Figure 12 Unit Weight Measurement of concrete

3.3.4 Compressive strength test

The specimens for compressive strength test, with 0%, 0.5%, 1%, 1.5% and 2%Enset fibers dosage was casted and cured in a water bath until they were tested according to (BS.1881)-111 "Method for normal curing of test specimens The compressive strength test (Figure 13) was performed following (BS.1881, 1983)"Method for determination of compressive strength of concrete cubes". In order to gain information on the rate of compressive strength gain with age, compressive strength tests were conducted at 3, 7, and 28 days for all concrete mixes. In each category three cubes was tested and their average was reported. A 3000 kN capacity compression testing machine was used for loading the specimens. The loading rate on the compression machine was kept constant. The specimen was loaded until failure and the ultimate load was recorded. The compressive strength was calculated by dividing the ultimate load by the cross sectional area of the specimen.

Figure 13 Compressive strength testing.

3.3.5 Flexural strength test

Specimens For flexural strength test, with 0%, 0.5%, 1%, 1.5% and 2% Enset fibers dosage of C-30 grade concrete was casted and cured in a water bath until they were tested, follows ASTM C 192 “Practice for Making and Curing Concrete Test Specimens in the Laboratory”. The flexural strength test (Figure 14) was performed following ASTM C 78 “Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)”.In order to gain information on the rate of flexural strength gain with age, flexural strength tests were performed at 3, 7, and 28 days for all concrete mixes. Load and corresponding deflections was recorded up to failure. In each category three beams was tested and their average was reported. The flexural strength calculation is as follows.

$$\text{Flexural strength (MPa)} = (P \times L) / (b \times d^2),$$

Where, P = Failure load,

L = Centre to centre distance between the support = 400 mm,

b = width of specimen=100 mm,

d = depth of specimen= 100 mm.

Figure 14 Flexural strength test of concrete.

From each category the mid-span deflections were obtained for single sample at the age of 28 days by using two high precision linear voltage differential transformers (LVDTs) that were placed on each side of the specimen. A rectangular sheet metal fastened to the specimen was also used to hold the LVDTs in place.

3.3.6 Split tensile strength test

For Split tensile strength, 36 specimens for C-30 grade of concrete with 0%, 0.5%, 1%, 1.5% and 2% Enset fibers was casted and cured according to ASTM C 192 “Practice for Making and Curing Concrete Test Specimens in the Laboratory”. The Split tensile strength (Figure 15) was done following ASTM C-496 “Standard Method of Test for splitting tensile Strength of Cylindrical Concrete specimen”. In order to gain information on the rate of Split tensile strength gain with age, Split tensile strength tests were performed at 3, 7, and 28 days for all concrete mixes. In each category three specimens was tested and their average was reported.

Figure 15 Tensile strength test of concrete

3.3.7 Restrained plastic shrinkage crack measurements

The restrained plastic shrinkage test was performed in accordance with the ASTM 1579 **"**Standard test method for evaluating plastic shrinkage cracking of restrained fiber reinforced concrete using steel inserts"with slight modifications.(ASTM 1579, 2006), is a test method developed mainly in order to compare the plastic shrinkage cracking behavior of different concrete mixtures containing any fiber reinforcement under prescribed conditions of restraint and moisture loss that are severe enough to produce cracking before final setting of the concrete . However, its application is not limited to only fiber reinforced concrete and can be possible to study other parameters as well.

The big metal notch insert in the middle, is the stress riser which acts as a crack initiation point and the other two smaller metal inserts on the sides serve as internal restraints (figure 16). It expected that Plastic shrinkage cracking is to occur above the stress riser.

In the experiments performed in this particular project internal temperature addition to the atmospheric variables were continually measured during the test. The test continues until the time of final setting is reached. At 24 hours after mixing the average crack width is determined. Moreover, ASTM C 1579 suggests a Cracking Reduction Ratio (CRR), which defines the percentage of reduction in the crack width in the Fiber-Reinforced Concrete (FRC), as:

$$\mathbf{CRR}= \left[1-\frac{\textbf{Avarage crack width of Fiber Reinforced concrete}}{\textbf{Avarage crack width of control concrete}}\right]*100\%$$

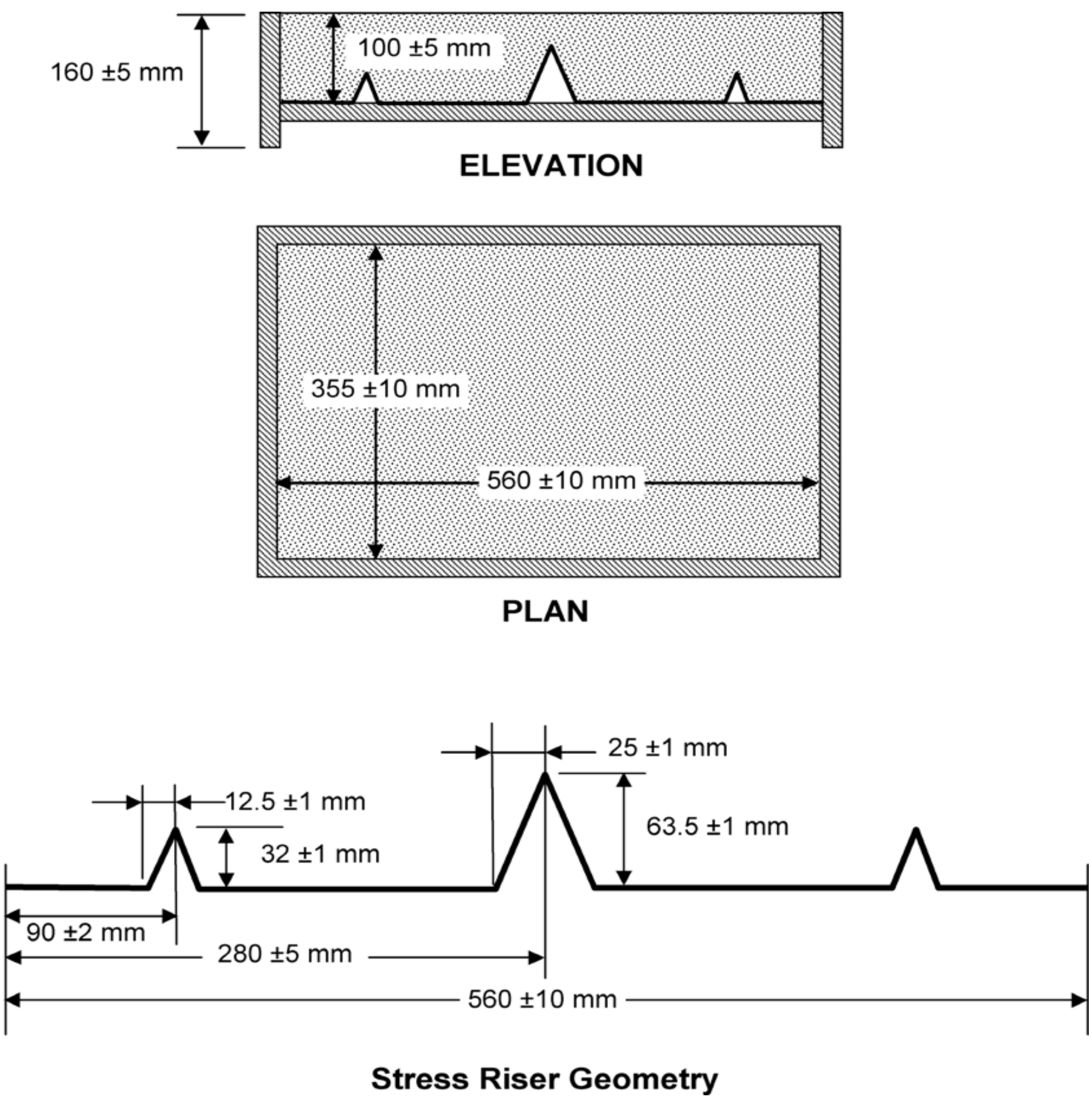

Figure 16: (ASTM C 1579) Standard mold to measure restrained plastic shrinkage

Specimen preparation

Concrete was mixed using pan mixer having a capacity of 25 liter. Plain concrete was prepared in accordance with ASTM C 192 "Practice for Making and Curing Concrete Test Specimens in the Laboratory". After the mixing the plain concrete, the Enset fiber was slowly added to the fresh concrete as within 4 minutes to evenly distribute fiber throughout the concrete(Figure 17). After adding the fibers, the operator stopped the mixer for about 2 minutes and scraped the side wall and bottom of the mixer pan. A final mix was then conducted.

Figure 17 Adding Enset Fiber to fresh concrete

The concrete specimens were casted by using restrained slab mold made for this experiment by following (ASTM C 1579). A thin layer of oil coated the surface of the metal inserts and the mold sides, in order to reduce bond between the concrete and mold as indicated in. After mixing, the concrete was poured into the slab mold and exposed to a specific environment.

The fresh concrete samples filled in to molds and vibrated using table vibrator and the concrete surface was smoothened by using a smooth steel trowel as indicated in Figure 18.

Figure 18: Smoothing concrete surface using steel trowel

Environmental conditions

A test set up was prepared specifically for this experiment, as shown in Figure 19. The environmental conditions used in this study were temperature of 36±3 ºc, relative humidity of 30±10%,and wind velocity of above 4.7 m/s. A 50 cm wide fan was used to produce wind with constant velocity on the slab surface and flood light was used to simulate rise temperature. The slabs were then checked visually for any signs of cracking at approximately 30-min intervals. The slabs (inside the molds) were kept in this environment for 24 h and image was captured.

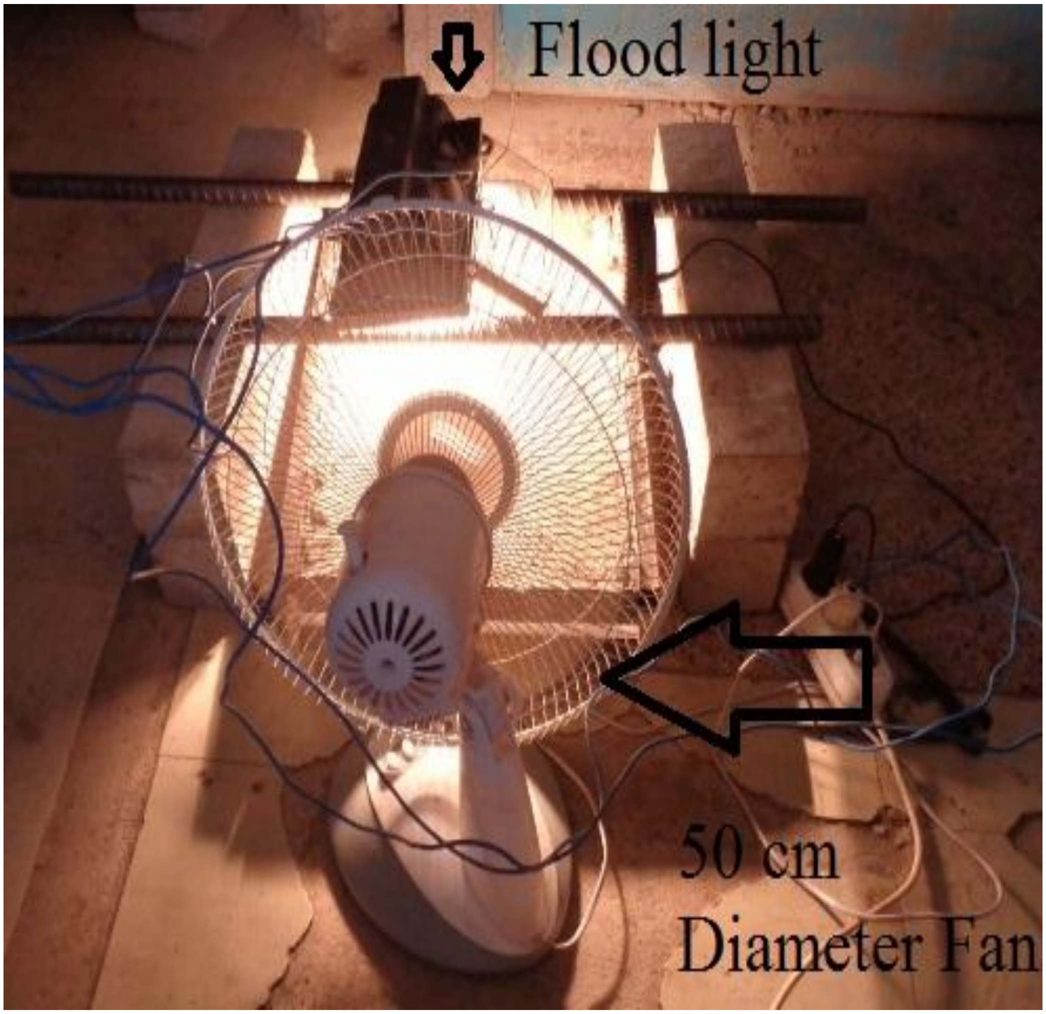

Figure 19 Test set up

Evaporation rate

Wind velocity, relative humidity, Test temperature and concrete temperature at the middle depth of the slab was measured using equipment's shown in (Figure 20) every 30 minutes up to 7 hr starting from the time water added.

Figure 19 Equipments to measure environmental conditions

Bleeding rate

After removal of bleed water at the surface of concrete using syringe, Weight loss of concrete was measured every 30 minutes using an electronic balance. The concrete sample used for the measurement of bleeding rate was prepared as the restrained slab specimen and had the same depth as the restrained slab. Weight loss due to bleeding was monitored using cylindrical specimen casted with the same mix proportions that were used for the restrained slab test and with same thickness with the slab.

Image Analysis

Within the initial setting time of cement, the restrained slab specimens were transferred in to the test setup .weight loss and plastic shrinkage cracking were checked for the first 6 hours. But the slabs were stored in the setup for additional 18 hours. After 24 hours the slabs removed from the set up and photographed for image analysis.

Sobel edge detection algorithm was used on an image of concrete to detect concrete crack. **MAT LAB** environment was used in obtaining analysis. The Sobel edge detection algorithm detects the concrete crack as continuous line. The other misdetections were eliminated by using line continuity algorithms.

4 RESULTS ANDDISSECTIONS

4.1 Slump Value:

The experimental investigation carried out, indicates that, the reduction of slump with increase in fiber observed (Figure 21) especially beyond 1.5% dosage.

Table 6 Slump values with different fiber content

Fiber Content (%)	Code	Slump (mm)	Picture
Normal Mix	EF0	190	
With 0.5% Fiber	EF0.5	94	
With 1.0 % Fiber	EF1.0	31	
With 1.5 % Fiber	EF 1.5	6	
With 2.0 % Fiber	EF2.0	0	

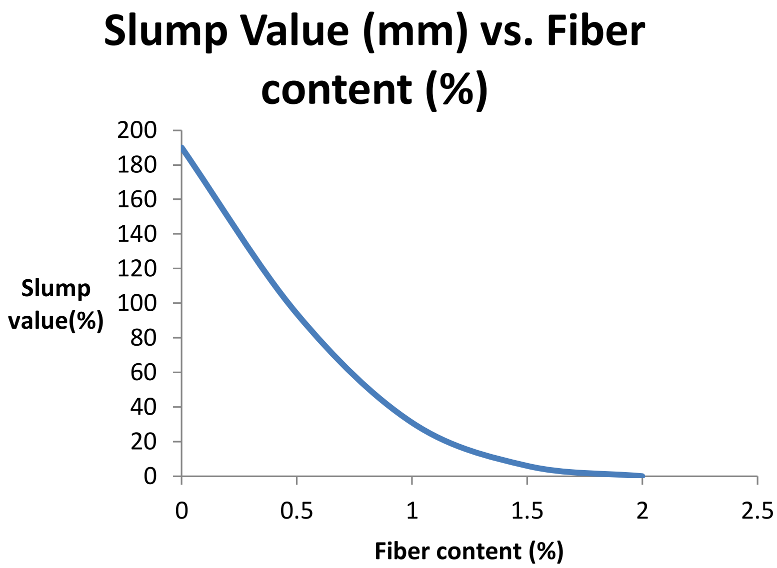

Figure 20 **Slump value vs. Fiber content**

4.2 Unit Weight of Concrete

The density (unit weight) of concrete ASTM C-138 was measured using a 5 liter standard mold. Little variation in density has been observed with varying percentages of Enset Fiber as indicated in Table 7.

Table 7 Unit Weight of Concrete

Fiber Content (%)	Code	Unit Weight (Kg/m^3)
Normal Mix	F0	2456.8
With 0.5% Fiber	F0.5	2496.8
With 1.0 % Fiber	F1.0	2452.3
With 1.5 % Fiber	F1.5	2489.6
With 2.0 % Fiber	F2.0	2421.5

4.3 Evaporation Rate

Evaporation rate were calculated from measured relative humidity, wind velocity, air temperature and concrete temperature using (Uno, 1998).

4.4 Crack initiation

Crack initiation for each restrained slab was checked starting from 30 minutes after water added to the concrete. The result (Table 8) shows that initiation time increased with increment in fiber content.

Table 8 Crack Initiation time

Fiber Content (%)	Code	Crack Initiation Time (min)
Normal Mix	F0	40
With 0.5% Fiber	F0.5	150
With 1.0 % Fiber	F1.0	420
With 1.5 % Fiber	F1.5	450

4.5 Compressive strength

The results of the compressive strength tests at three different specimen ages (3 days, 7 days and 28 days) are listed in Table 9, and illustrated in Figure 22 and Figure 23. As can be seen from the test results, Addition of the Enset fiber in the concrete mix has a little effect on its compressive strength. With increasing fiber content up to 1.5 % fiber dosage, compressive strength of concrete increased slightly but with 2% of Enset fibers the compressive strength decreased may be due to dispersion problem of Enset fiber at this specific dosage.

Table 8 Compressive strength results of concrete specimens

Fiber Content (%)	Code	Compressive strength (Mpa)		
		3 days	7 days	28 days
Normal Mix	EF0.0	18.6	26.9	41.5
With 0.5% Fiber	EF0.5	19.4	27.4	42.1
With 1.0 % Fiber	EF1.0	20.1	29.8	43.2
With 1.5 % Fiber	EF 1.5	23.2	31.2	43.8
With 2.0 % Fiber	EF2.0	16.2	23.9	29.8

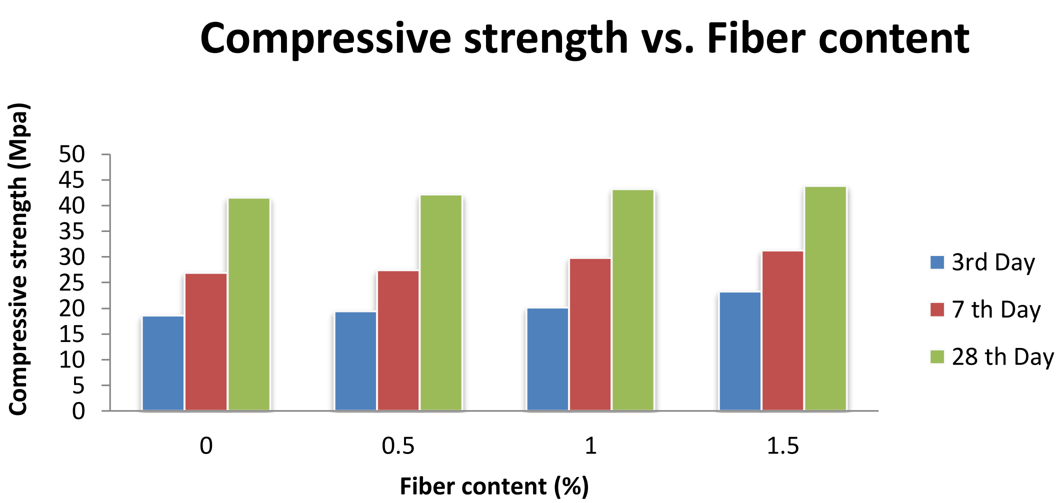

Figure 21 Variation of Compressive Strength with Fiber content

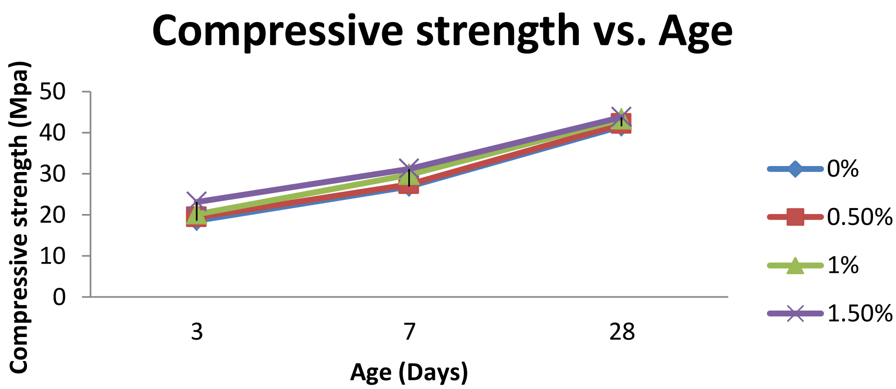

Figure 22 Variation of compressive strength with age

4.6 Flexural strength

The results of the flexural strength tests at three different specimen ages (3 days, 7 days and 28 days) are listed in Table 10, and illustrated in Figure 24 and Figure 25. As can be seen from the test results, almost all mixtures had low modulus of rupture. This is typical of an ordinary concrete which had low flexural strength. By adding up to 1.5 % fiber dosage in to the mixture, Flexural strength was increased only to a small degree but with 2% of Enset fibers the Flexural strength of concrete decreased may be due to dispersion problem of Enset fiber at this specific dosage.

Table 9 Flexural Strength results of concrete specimen

Fiber Content (%)	Code	Flexural strength (Mpa)		
		3 days	7 days	28 days
Normal Mix	EF0.0	1.90	2.54	3.25
With 0.5% Fiber	EF0.5	1.89	2.59	3.36
With 1.0 % Fiber	EF1.0	2.11	2.84	3.35
With 1.5 % Fiber	EF 1.5	2.23	2.86	3.42
With 2.0 % Fiber	EF2.0	1.57	2.39	3.02

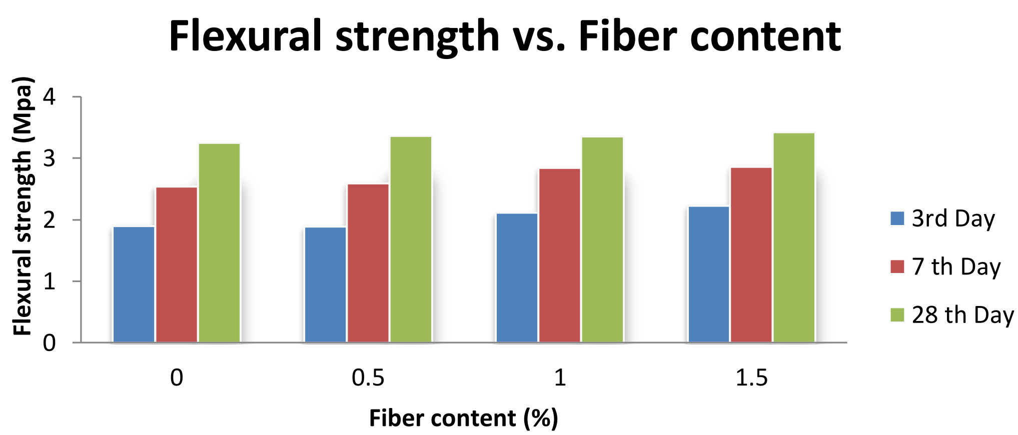

Figure 23 Variation of Flexural strength of concrete with Fiber content

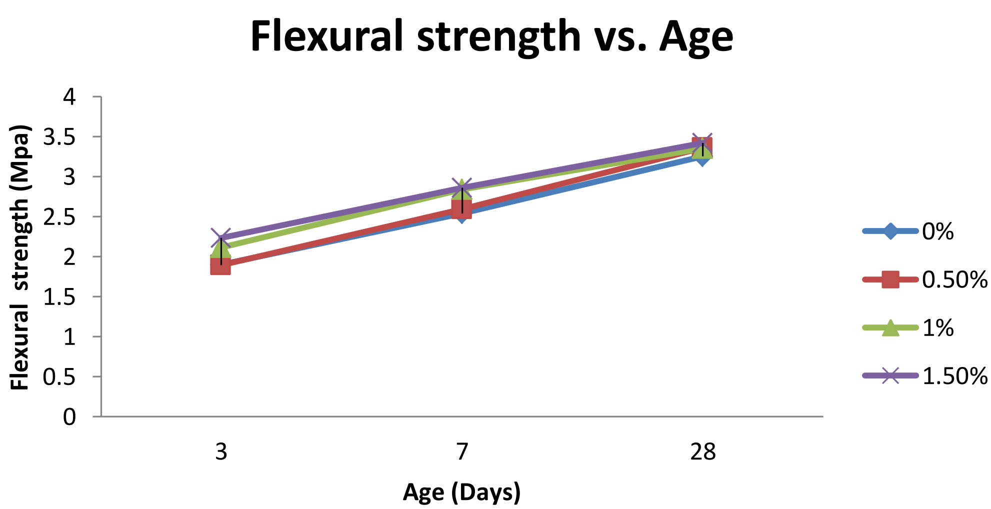

Figure 24 Variation of Flexural strength of concrete with age

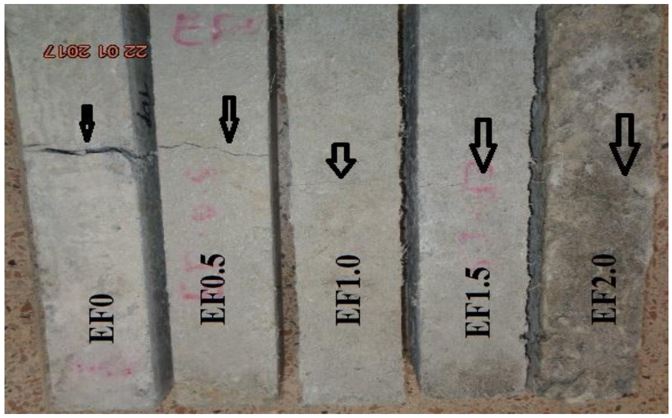

Figure 25 Typical Failure modes of beam under flexural load.

Figure 28 shows Load vs. deflection curves for the Enset fiber reinforced concrete mixes at the age of 28 days with varying percentages of Enset Fibers. It is observed that as fiber content increase the failure mode changes brittle failure to ductile. The test results shown that, Enset fibers added post peak load carrying capacity suggesting their effectiveness in controlling propagation of cracks after their initiation (Figure 27).

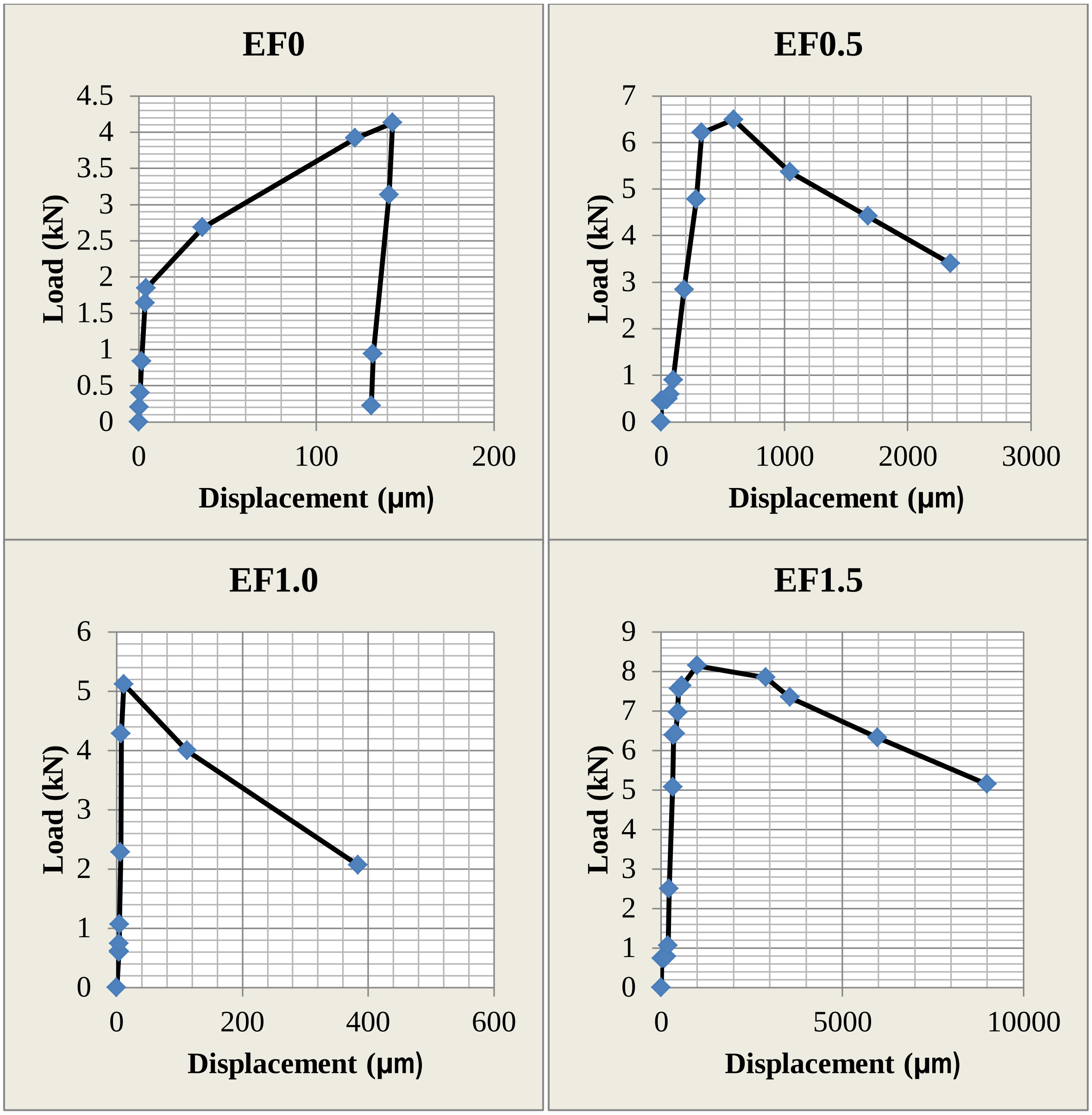

Figure 26 Load vs. Displacement curve of Enset fiber reinforced concrete

4.7 Split tensile strength

Concrete tensile split strength test results are given in Table 11. Relationship between the Enset fiber content and corresponding concrete tensile split strength with respect to the control concrete are shown in Figure 29 and Figure 30. It is observed that, addition of Enset fibers to a concrete mixture is advantageous to the tensile properties of concrete. The fibers act as crack arresters (Figure 28) in the concrete matrix. Tensile splitting strength of concrete was found more than the control (0% fiber) concrete with fiber addition up to about 1.5% above which the tensile strength was found lower than the control concrete due to balling effect.

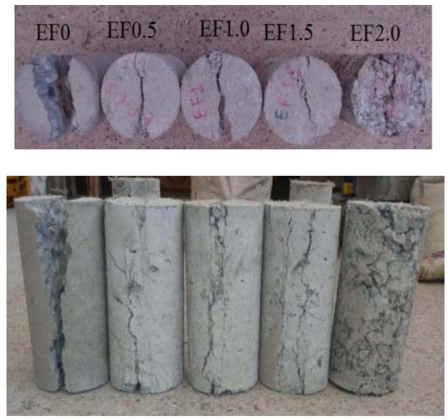

Figure 27 Typical Failure modes of cylinder under splitting load.

Table 10 Tensile Strength results of concrete Specimen

Fiber Content (%)	Code	Tensile strength (Mpa)		
		3 days	**7 days**	**28 days**
Normal Mix	EF0.0	1.2	1.32	2.9
With 0.5% Fiber	EF0.5	1.24	1.48	3.1
With 1.0 % Fiber	EF1.0	1.29	1.56	3.15
With 1.5 % Fiber	EF 1.5	1.35	1.57	3.42
With 2.0 % Fiber	EF2.0	1.1	1.2	2.6

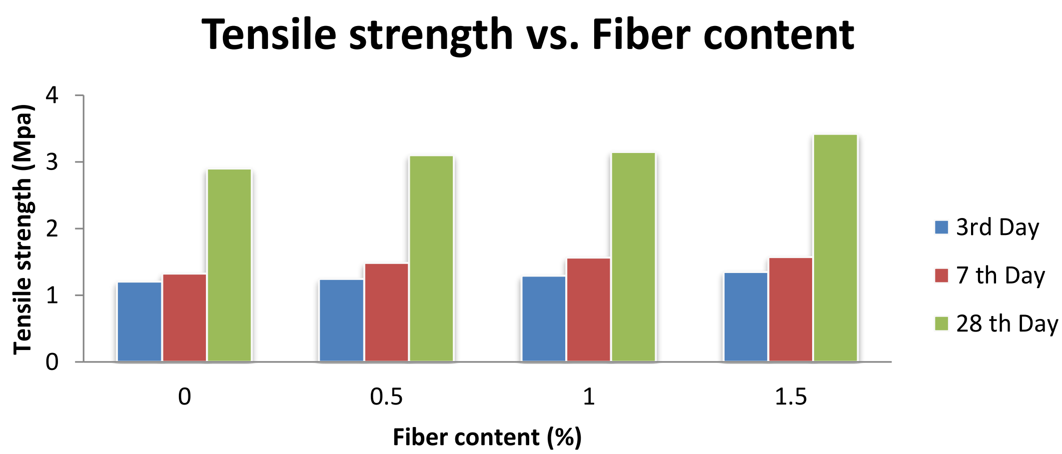

Figure 28 Variation of Tensile with Fiber content

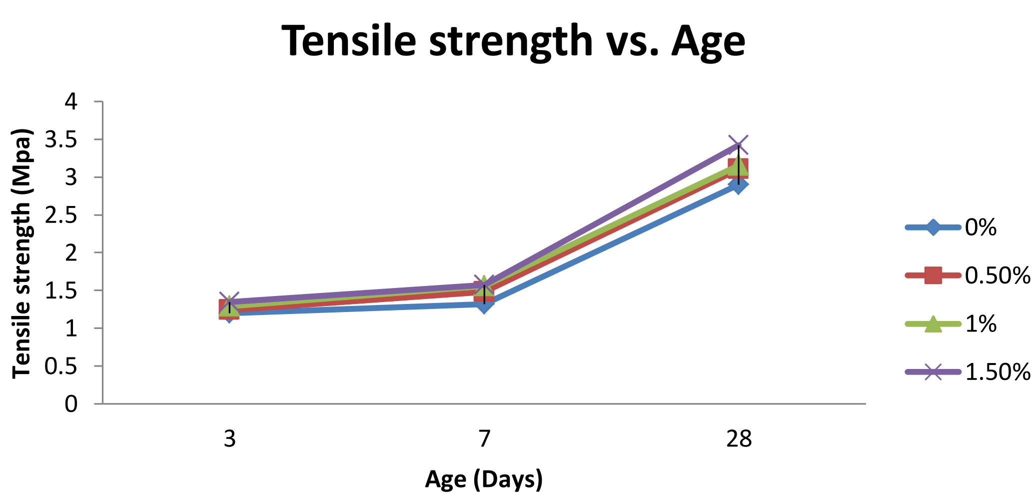

Figure 30 Variation of Tensile strength of concrete with age

4.8 Restrained Plastic Shrinkage tests

After casting the samples on the restrained slab mold, the specimens were placed in the controlled temperature and humidity set up and observed periodically. For control concrete, approximately after 40 minutes (since the onset of casting), a fine hairline crack was observed running throughout the width of the slab. This fine crack was found to widen upon further drying. In case of Enset fiber reinforced concrete specimens, the appearance of the first crack took as long as more than 1 h. Samples of shrinkage cracked concrete are shown in Figure31. These phenomena could be attributed to the availability of bleed water on the top surface, which delays drying of the surface and possible reinforcing the concrete by the Enset fiber.

Figure 29 Typical plastic Shrinkage occurred zoomed crack in concrete slabs

Images of the cracks were taken using a digital camera having 20.1 Mega pixels. Then, the images were processed and edited with image analysis software to get a clear crack profile. The images were then analyzed by computer image analysis software to quantify the percentage area cracked. Crack measurements comprise of the crack width (average) and percentage of total crack area. Example images after the processing operations are given in Figure 32.

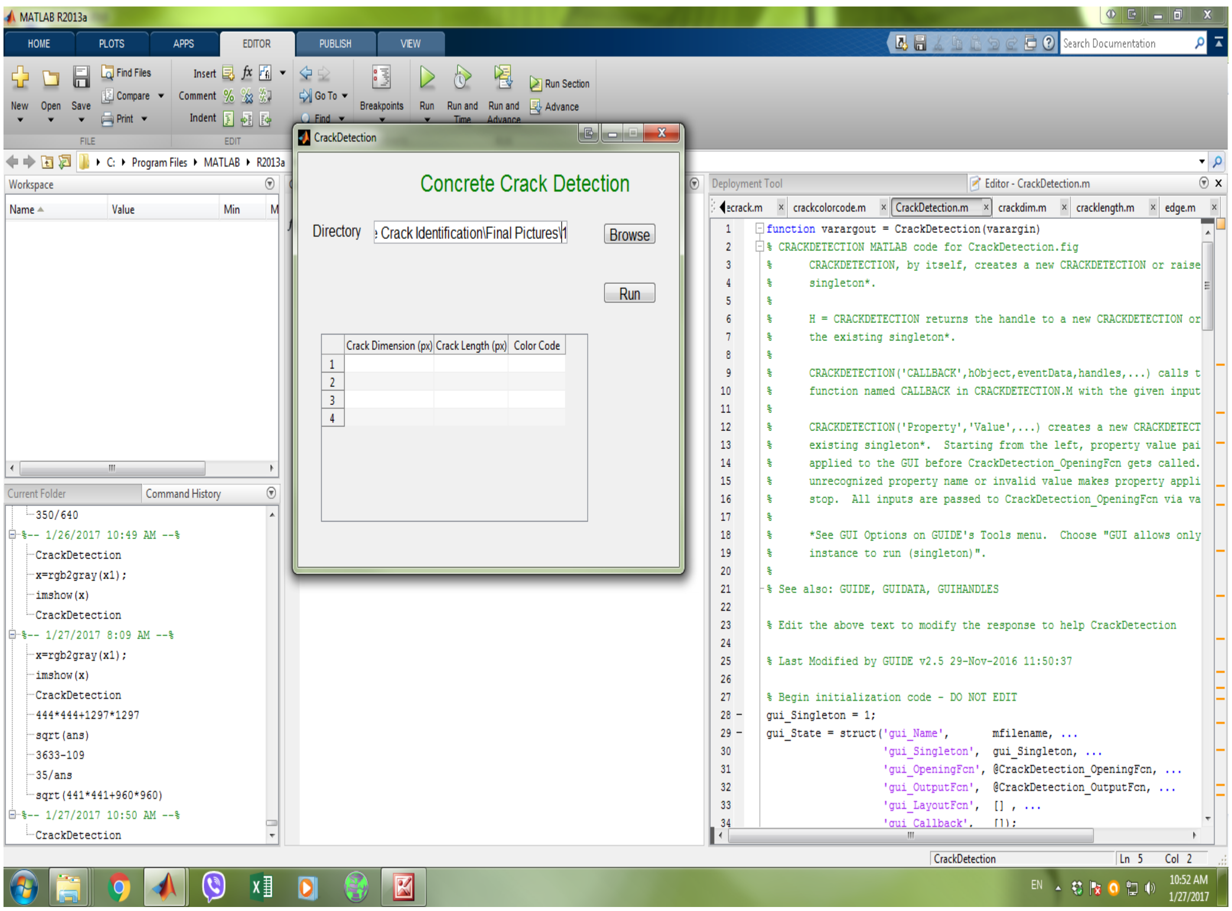

Figure 30: Image analysis for shrinkage crack

The edited image was then analyzed and a total crack width was also estimated using computer software. A picture of overall procedure is shown in Figure 32. The results obtained from image analysis are shown Table 12.

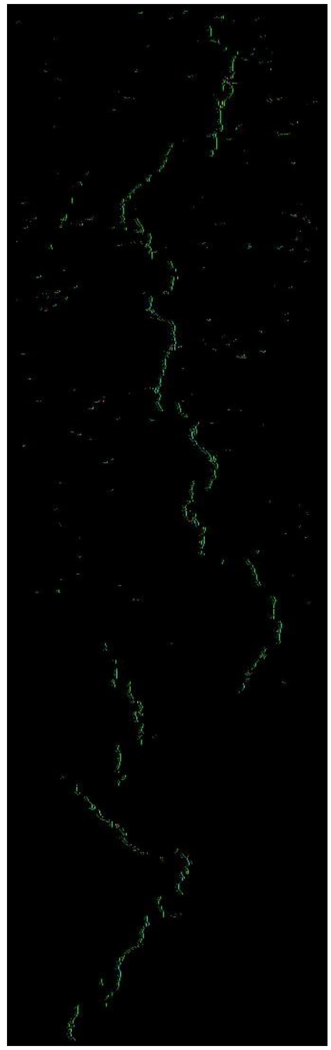

Figure 31 Shrinkage crack in concrete slabs

4.8.1 Crack Patterns

As indicated in Figure 34, the control concrete has less narrow width's of cracks(<0.4 mm) however the quantity of wider cracks(about 1 mm) is more relative to the other specimens. This is possibly due to the absence of crack arrest mechanism attributed to the presence of the Enset fibers. Thus, the initially formed plastic shrinkage cracks are expected to simply widen without any stitching effect.

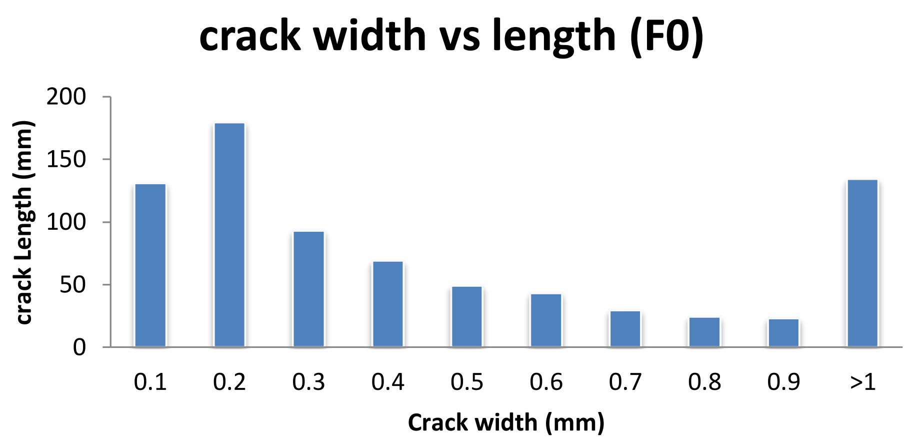

Figure 34 Histogram of crack occurrence of control concrete

For concrete with 0.5 % Enset fiber content, it can be shown from (Figure 35) that narrow width cracks are greater than control concrete but wider cracks (> 1 mm) are less relative to control concrete. It indicates that the Enset fibers are playing an important role in stitching some of the cracks that occurred during plastic period.

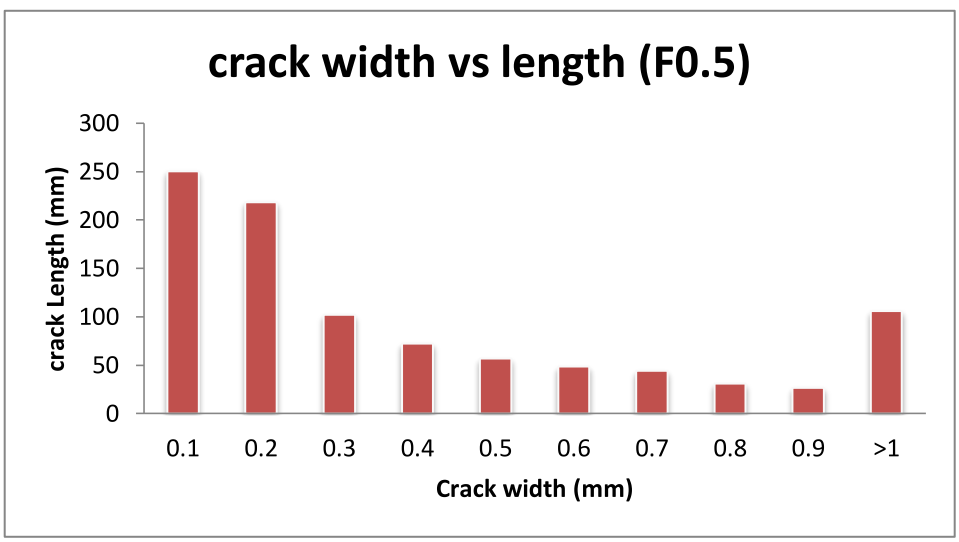

Figure 32 histogram of crack occurrence of concrete with 0.5 % Enset Fiber

For concrete that contains 1% Enset fiber the quantity of cracks having width up to 0.2 mm are greater than that of both control concrete and concrete with 0.5 Enset fiber contents. But cracks wider than 0.2 mm are dramatically decreased (Figure 36). This indicates that most of the cracks occurred prevented from widening.

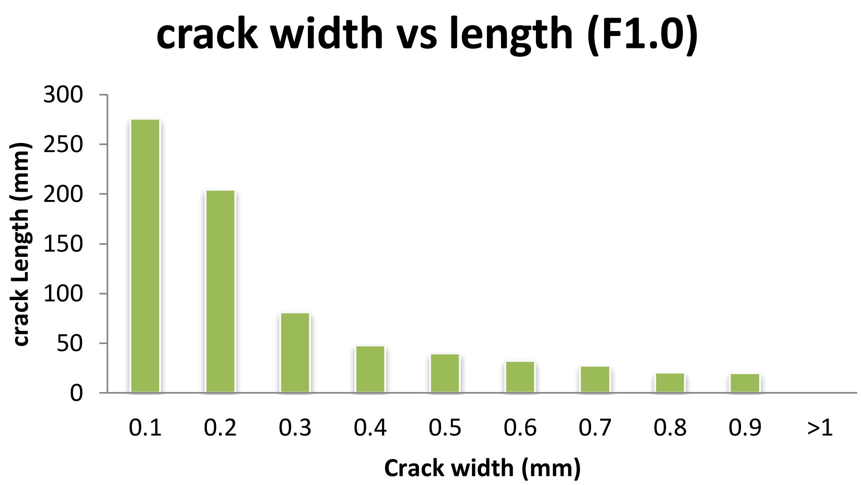

Figure 33 histogram of crack occurrence of concrete with 1 % Enset Fiber

At 1.5 fibers content quantity of crack up to the width of 0.1 mm is greater than control concrete but less than both samples having 0.5% and 1.0% of Enset fiber. However, cracks with width greater than 0.1 mm are remarkably reduced (Figure 37). This result indicates that Enset fiber at 1.5% content effectively arrests the plastic shrinkage cracks that already formed at the plastic state.

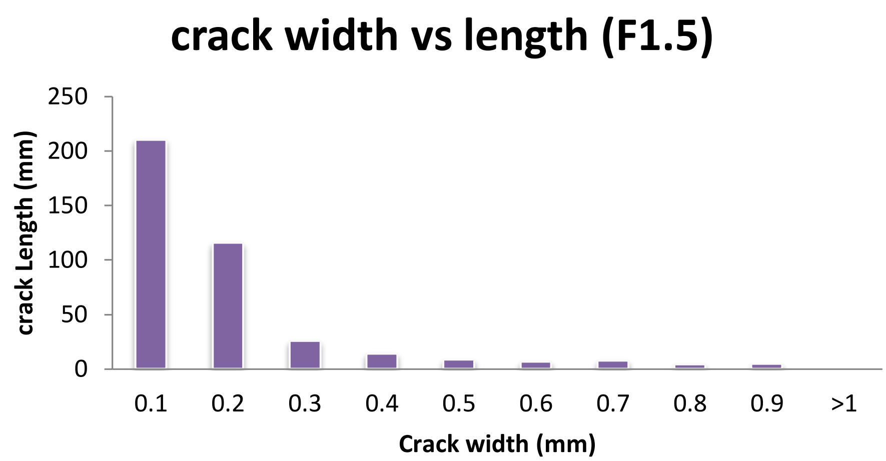

Figure 34Histogram of crack occurrence of concrete with 1.5 % Enset Fiber

The crack-map for the four samples with and without fibers is analyzed using image analysis. Accordingly, the cracks widths and lengths with varying percentages of Enset fiber are illustrated in Figure 38.

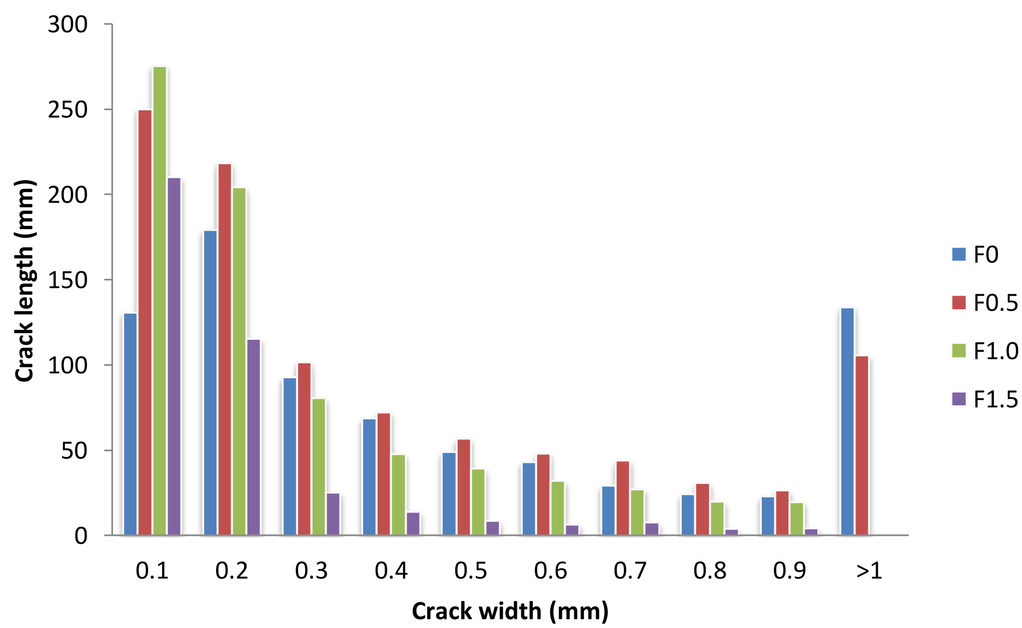

Figure 35 Histogram of that shows total Crack found from image analysis

Table 11 Crack characteristics of fiber reinforced concretes.

Fiber Content (%)	**Code**	**crack area (mm^2)**	**Avg. crack width (mm)**	**Reduction of crack (%)**
Normal Mix	F0	777.4	0.45	_
With 0.5% Fiber	F0.5	370.23	0.39	14.38
With 1.0 % Fiber	F1.0	203.54	0.27	39.84
With 1.5 % Fiber	F1.5	77.91	0.20	56.59

The percentage of plastic shrinkage crack decreases with addition of Enset fiber as shown in Figure 39. With the addition of 1.5 % fibers, the cracks are visibly restrained from widening compared to that of the control sample**.** The plastic shrinkage crack width reduced by 56 % with the addition of fiber up to 1.5%. In general, Enset fiber could act as crack-bridge and therefore, contribute the reduction of plastic shrinkage cracking risk.

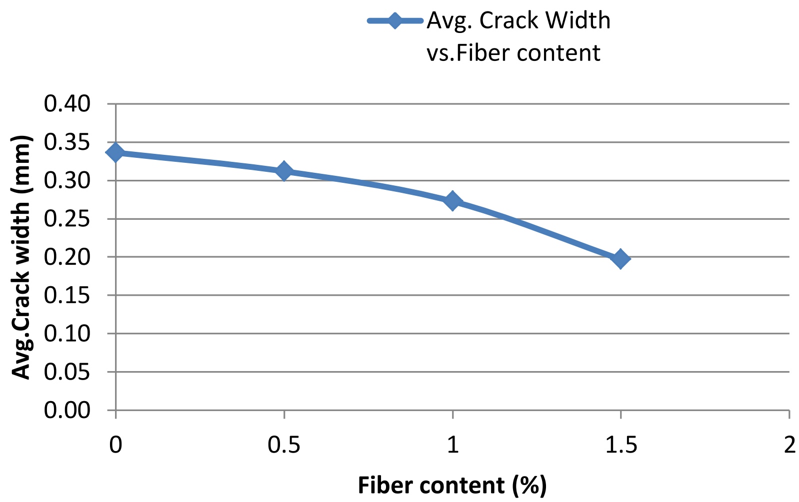

Figure 36 Relationship between fiber content and crack width of concrete

5 CONCLUSIONS

Experimental investigation of plastic shrinkage cracks in concrete is studied using locally available non-metallic fiber, produced from Enset using image analysis. The following conclusions can be drawn from the investigation carried out in this study and are summarized as follows;

- Enset fibers are effective in bridging plastic shrinkage cracks that occurred during Fresh state concrete.
- With the addition of Enset fiber (0.5–1.5 %) the compressive strength of concrete increased by 1.5–5.5% and the Flexural strength of the concrete increased by about 3.4–5.2% which is minor compared to the control concrete. The optimum fiber content for the compressive and flexural strength is 1.5 % but at fiber content of 2% both the compressive strength and flexural strength decreases may be due to fiber dispersion problems above 2% fiber dosage.
- About 18% increases on tensile strength was observed at 28 days with 1.5 % Enset fiber addition.
- With an increase in Enset Fiber content (1.5%), the crack width significantly reduced by 56 %. In general, addition of 1.5% Enset fiber was found to be advantageous for concrete to reduce plastic shrinkage crack of concrete pavements without negatively affecting physical properties of concrete.

Overall, the addition of Enset Fiber was found advantageous to remarkably reduce the plastic shrinkage crack of concrete, thereby contributing to the durability performance of rigid pavements. Furthermore, the addition of Enset fibers also positivity contributed to the enhancement of mechanical properties of concrete and its post peak tensile ductility.

6 RECOMMENDATION

Enset fiber can be used in pavement construction to reduce plastic shrinkage cracking risk. In addition I recommend future researchers on this area of study to include the following points

- Effect of Enset fiber length on plastic shrinkage
- Durability of Enset fiber reinforced concrete should be studied
- In this paper the full depth of concrete was mixed with Enset fiber .But it is required only on top parts of concrete sections to reduce plastic shrinkage crack risk so research should be done on how to apply the fiber only on top parts of concrete sections.

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APPENDIX

Evaporation rate calculated using (Uno, 1998)

Time (min)	Wind Velocity (km/hr.)	Relative Humidity (%)	Test Temperature (°c)	Concrete Temperature (°c)	Evaporation (kg/m²/hr)
			F0		
30.00	18.00	31.00	36.20	18.00	0.73
60.00	17.28	36.00	32.40	18.20	0.69
90.00	17.64	32.00	38.20	18.60	0.73
120.00	18.72	39.00	39.10	19.20	0.69
150.00	16.92	29.00	37.20	19.40	0.79
180.00	17.64	24.00	34.30	20.10	0.91
210.00	18.00	28.00	36.20	20.90	0.94
240.00	17.28	31.00	36.40	21.50	0.92
270.00	17.28	29.00	37.60	22.40	0.99
300.00	16.92	32.00	36.30	23.40	1.02
330.00	17.64	34.00	36.20	23.60	1.05
360.00	17.64	32.00	33.20	24.10	1.13
390.00	17.28	34.00	31.50	24.60	1.14
420.00	17.28	36.00	32.60	24.80	1.12
			F0.5		
30.00	17.28	29.00	36.20	18.20	0.73
60.00	17.64	28.00	36.40	19.60	0.84
90.00	16.92	31.00	37.20	20.30	0.82
120.00	18.72	36.00	36.20	21.40	0.92
150.00	18.36	32.00	38.30	21.30	0.93
180.00	19.08	33.00	34.30	21.70	1.00
210.00	18.00	32.00	38.00	21.90	0.96
240.00	17.28	35.00	37.70	22.30	0.92
270.00	16.56	33.00	36.90	22.50	0.93
300.00	17.64	39.00	34.40	22.80	0.95
330.00	18.00	36.00	36.70	23.60	1.04
360.00	18.72	32.00	36.80	23.80	1.14
390.00	18.36	33.00	36.90	24.10	1.13
420.00	18.00	33.00	36.20	24.10	1.12

F1.0					
30.00	18.72	31.00	34.20	17.40	0.73
60.00	18.36	32.60	34.50	17.50	0.70
90.00	19.08	32.00	35.60	18.20	0.77
120.00	18.72	33.00	36.20	18.60	0.77
150.00	18.36	34.00	34.90	18.90	0.77
180.00	17.64	33.50	35.00	20.10	0.83
210.00	17.28	33.00	36.30	21.80	0.92
240.00	17.64	32.00	37.20	21.90	0.95
270.00	17.64	36.00	34.60	22.40	0.95
300.00	17.64	34.00	32.10	22.60	1.01
330.00	18.00	32.00	36.20	22.42	1.00
360.00	17.28	31.00	35.20	23.60	1.07
390.00	17.28	36.00	35.60	23.80	1.03
420.00	17.64	31.00	35.70	24.30	1.14
F1.5					
30.00	17.28	29.00	33.20	18.20	0.75
60.00	17.28	32.00	34.60	18.40	0.73
90.00	18.72	32.00	36.20	18.90	0.80
120.00	18.36	29.00	33.40	19.00	0.84
150.00	18.36	27.00	37.20	19.10	0.84
180.00	16.92	29.00	36.50	19.30	0.78
210.00	16.92	33.00	34.60	19.90	0.79
240.00	17.28	32.00	36.90	20.20	0.82
270.00	16.92	32.00	35.00	21.70	0.91
300.00	17.28	30.00	33.40	22.10	0.98
330.00	17.64	31.00	34.80	22.60	1.02
360.00	17.28	31.00	36.00	22.90	1.02
390.00	17.28	33.00	34.90	23.40	1.04
420.00	16.92	32.00	37.20	25.20	1.15